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NO. 7 – BOTANY
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By C. M. Eardley

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[Read 8 April 1948]

With Map

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INTRODUCTION

In the course of determining the plants collected on the Simpson Desert Expedition, 1939 (Eardley (36)), considerable interest was aroused in the question of how the Simpson Desert compared in aridity with other great deserts of the world.

Information was now available on the vegetative cover of the Simpson Desert, so a search was made for similar literature about seven other deserts which contained parallel sandridges. As far as possible, meteorological data and relevant general descriptions were also sought, but the emphasis was on the vegetation, and the results are now presented in this study. It is felt that a useful measure of comparative aridity has been obtained.

(A) LIBYAN DESERT

The eastern half of the Sahara is now generally referred to as the Libyan Desert. Gautier (5) stresses the difference between the Occidental and the Oriental Sahara, saying that in essence it is due to "the extreme aridity of the Libyan Desert, incomparably greater than that of the Occidental desert" (p. 105, *op. cit.*).

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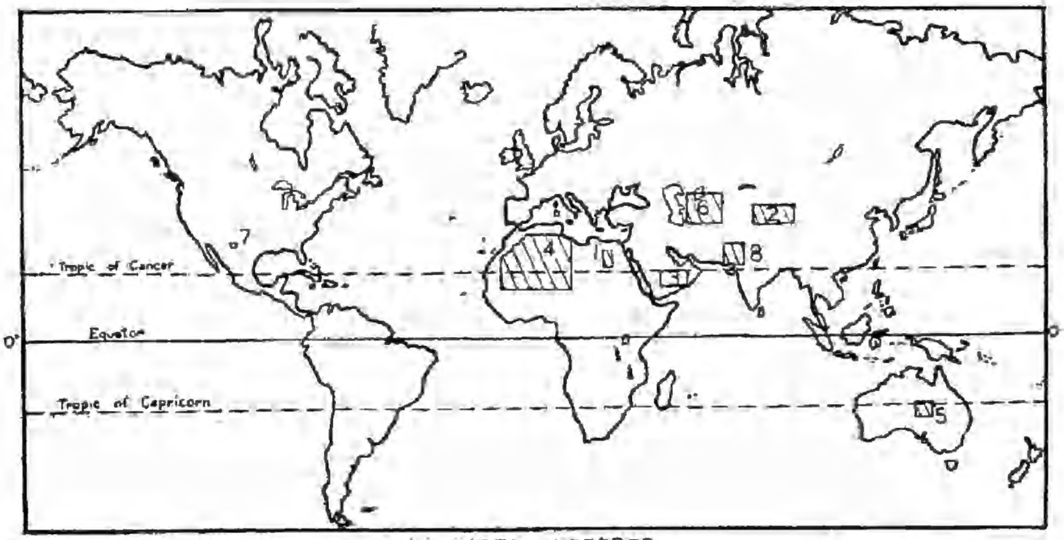
* Herbarium of the University of Adelaide.

Authorities for extra-Australian plant names have only been given in this paper when supplied in the source quoted.



SAND-RIDGE DESERTS

1. Libyan Erg 3. Rub' al Khali 5. Simpson Desert 7. Chihuahua
2. Takla Makan 4. Western Sahara 6. Kara Kum and Kisil Kum 8. Thar Desert

The Libyan Desert consists mainly of flat expanses covered with a stony surface or a sand sheet; it also includes areas of various sizes where sand-dunes occur. These dunes are distinguished by their tendency to form long parallel lines whose regional orientation depends upon the direction of the prevailing winds in the locality. It is these dune-areas which are of so much interest to the present study. By far the largest of them is the Great Libyan Erg which Gautier considers "probably the most imposing mass of dunes on the whole surface of the earth" (p. 103, *op. cit.*), with nothing comparable to it in the Occidental Sahara. The smaller dune-areas will here be neglected in order to concentrate attention on the Great Libyan Erg, which Rohlfs (8) called the "Great Sand Sea." Knowledge of this region, even of its extent, has been almost entirely lacking until about 1930. It is the most inhospitable part of the barren Libyan Desert.

A summary of recent explorations in the Libyan Desert is given in Bagnold's popular book, "Libyan Sands" (2). His own desert journeys by motor car were most extensive and included excursions into the Great Sand Sea in 1929 and 1930 (1). The only published account then available was that of Rohlfs' historic journey of 1874 (8).

The Great Sand Sea lies against the western border of Egypt. It forms an area roughly rectangular and about 300 miles long by 100 miles wide; the long axis lies N.N.W. by S.S.E., and this is also the direction of alignment of the long parallel dunes (just as in the Simpson Desert, as it happens). There is a narrow plateau between the dunes and the coast in the north, and the oasis of Siwa is situated at the base of the southern escarpment of this plateau, close to the northern dunes. Another formidable barrier, the eastern escarpment of the great Gilf Kebir Plateau, lies to the south of the Sand Sea; it is therefore very difficult to leave Egypt by the western frontier except in the extreme north and perhaps the extreme south.

Among the names famous in the exploration of the Libyan Desert, only a very few can add to our knowledge of the interior of the Sand Sea. These are Rohlfs (8), de Lancey-Forth (4), Bagnold (1 and 2), Wingate (11), P. A. Clayton and Lady Clayton East Clayton (about 1933).

Rohlfs attempted to cross the dunes from east to west near the southern end with a well-equipped caravan of seventeen camels; he very soon found himself faced with the close, parallel sandridges over 100 metres high and from two to four kilometres apart (much higher and broader than the Simpson Desert dunes). He came to the conclusion that his camels would be exhausted after even four days of travel across such dunes, and regretfully turned his direction north-north-west for 300 miles along the lanes between the dunes to Siwa; on this occasion he travelled 420 miles in 36 days. Unfortunately, the original accounts of Rohlfs' journey have not been seen by the present writer, but it has been gleaned at second-hand (from Bagnold) that *Rohlfs saw no plants in the whole of the 300-mile journey in the dunes* except a little grass on nearing Siwa. Such an absence of plant life is highly unusual, even for a desert, though seen in other parts of the Libyan Desert, as described by MacDougal (7) and Thomas (10).

De Lancey-Forth, formerly commanding the Frontier Camel Corps, was inspired in his journeys by the search for the legendary oasis, Zerzura, as were many other explorers. His journeys into the Sand Sea were by camel. In the winters of 1921 and 1924 he went about 100 and 200 miles respectively, south of Siwa, the second journey being an extension of the first along the dune lanes. This route lay some 50 miles west of Rohlfs' route, but the western edge of the dunes was not seen. *In one or two sandy valleys he found odd, green bushes (un-named), too bitter for camels to eat, but there was no other vegetation.*

In 1922-23, de Lancey-Forth investigated the south-eastern edge of the dunes and penetrated them as far as Rohlfs had done before turning north-north-west. *The only vegetation found was in a valley thinly grassed for a mile or two.* It is probable that this valley lay on the track of a vaguely known and very difficult Arab caravan route across the southern dunes of the Sand Sea, connecting Kufra on the west with Dakhla Oasis on the east; Bagnold also saw this track in his journey presently to be described. De Lancey-Forth's Journeys were not published until 1930 (4).

Bagnold's travels, unlike these, were all by motor-car. He was among the pioneers who demonstrated the accessibility of big dunes to light motor-cars, and became very expert at negotiating them. P. A. Clayton also made extensive desert journeys by car. It may be argued that there is less chance of seeing any vegetation present when travelling by car, but the fact remains that, of the accounts seen, Bagnold's expeditions alone collected and named the one or two plant species found in the Sand Sea.

Bagnold attacked the dunes from Ain Dalla, making virtually three trips into them in 1929 and 1930. Ain Dalla is a small oasis about half-way along their eastern margin. He penetrated further westward than Rohlfs or de Lancey-Forth (1922), and found the mysterious caravan route between Kufra and Egypt, but he was unable to follow it out of the dunes on the west side and had to make his escape southwards along the lanes between them. This part of his journey took perhaps a fortnight, but he had travelled 700 miles in the dunes and seen more of the area than any of his predecessors, having crossed a great many of the dunes at right angles in both directions.

W. B. K. Shaw went with Bagnold as botanist. His collection of 21 species in all was identified at Kew, and his published notes on the vegetation of the actual Sand Sea (6, 1931) are most helpful. The only species he saw there was *Ephedra alata* var. *Decaisnei* Stapf., usually as single, isolated bushes 18″ high in pure sand. He also collected a piece of wood from the remains of a dead shrub in the heart of the Sand Sea; it was identified as another species of *Ephedra*. This genus contains several widespread desert plants and belongs to a group

represented in all the continents except Australia. Along the rarely used camel route across the dunes from Kufra, he saw the shrivelled remains of plants for some hundreds of yards, in places. They were not worth collecting, but he thought they might have been a species of the grass *Aristida*. Then, for great distances, he saw no plants at all save for rare tufts of the same small, withered grass. Within some miles of this route are the following two entries on Bagnold's map: "40 green bushes" and "200 green bushes" (1).

The other plants on Shaw's list were collected outside the Sand Sea and near wells. He also went with Bagnold in 1932 on a long round trip of 6,000 miles from Cairo and back, to the southern part of the Libyan Desert towards the Sudan, and collected a further 27 species, again identified at Kew and published with his notes (6, 1934).

For further information on the desert plants between the Nile Valley and the Sand Sea, the accounts of the botanists MacDougal (7) and Hamshaw Thomas (10) may be consulted. Both emphasise the absence of plant life for stretches of many miles and the poverty in number of species. It is of interest to note that several of the genera quoted by them are also characteristic of the Kara Kum Desert, *e.g.*, *Aristida*, *Calligonum*, *Salsola*, *Haloxylon*, *Ephedra*, and *Tamarix* which is important in all the Old World Deserts.

In 1933 Orde Wingate (also in search of Zerzura) actually crossed the dune belt from east to west about 130 miles, and returned on his own tracks; he travelled with camels on lat. 26½-27° N., crossing two of Bagnold's tracks and also Rohlfs'. Wingate was in the dunes 35 days. He saw *"several" brilliant green shrubs*, usually halfway up a dune. They were very bitter and only eaten sparingly by the camels (*c.f.*, de Lancey-Forth). He also recorded a couple of pieces of dead tamarisk trunks. It is not known whether the green bushes of Wingate and de Lancey-Forth were *Ephedra*, as in Bagnold's case.

Only allusions to the journeys of the Claytons have been seen by the present writer, and published accounts were sought in vain.

During the recent military campaigns in northern Africa (1940-3), certain small mobile units operated far south of the coastal strip on special missions; they traversed the desert by all modern means of transport, and there was some travelling in the Sand Sea with jeeps. Bagnold pioneered the formation of such units, and some popular accounts of their work have been published. One of these, (a) is written by W. B. K. Shaw, the botanist of earlier expeditions with Bagnold; another is by Malcolm James (b), however nothing is added to the precise botanical knowledge of the Great Sand Sea.

To attempt a formal account of the meteorology of the Sand Sea is not possible; Rohlfs probably records some useful information, and we know that he experienced rain there in 1874 (his book was unavailable to the writer). Bagnold, from his extensive knowledge, states that the amount of rainfall throughout the Desert is ill-known but conspicuously sporadic, and absent for perhaps eight years at a time. Engler (25) and Gautier (5) say the same thing, mentioning heavy local storms once in twelve years, and giving an apparent average of about 3·9″ annually in the French Sahara. Another factor is the large diurnal range of temperature in the erg or dune desert. Also, the air is very dry, with relative humidity usually under 20%, and evaporation from a free water surface is quoted as being 4 in. or more, yearly (MacDougal). The temperature drops quickly at night in the dunes, and in winter there may be nocturnal frosts, but nothing

(a) "Long Range Desert Group," Collins, London, 1945

(b) "Born of the Desert," Collins, London, 1945

to approach the winter cold of the Takla Makan. Dry winds are an important feature of the Libyan climate. Human inhabitants are few in number and confined to the larger of the oases; this is in contrast to the western Sahara, where there are small, nomadic tribes of camel herders.

To sum up, the Great Sand Sea is quite uninhabited, scarcely visited, and very difficult for travelling. With small exceptions the large parallel sandridges are bare of vegetation. Among the few plants which have been seen there and identified are *Ephedra alata* var. *Decaisnei* Stapf, and possibly another species of *Ephedra*, together with grass fragments, perhaps *Aristida* sp., and remains of supposed tamarisk (11) trunks.

These bare parallel dunes are very much more arid than the Simpson Desert, with its comparatively good cover of vegetation between the dunes at least; the Libyan dunes are also much higher.

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B. THE TAKLA MAKAN DESERT

The Takla Makan is the most terrible of all the five or six Asiatic desert regions, and probably comparable only with the worst parts of the Libyan and Sahara Deserts. It lies in Central Asia in the southern part of Sin-kiang, the western-most province of China. This elevated depression, also known as Kashgaria or Eastern Turkestan, is almost surrounded by some of the highest mountains in the world. On the north are the Tian Shan Mountains, on the south the mountains and plateau of Tibet, and on the west the Pamirs; to the east lies the Wandering Lake, Lop-nor, and the Takla Makan extends into the Gobi Desert.

These mountain barriers are considered by Popov (16) to account for the poverty of the vegetation of Kashgaria, so far as species numbers go, compared with the richness westward in the deserts of Asia Media; however, the inhospitable sand-dunes of the Takla Makan are hardly in need of this explanation for their lack of plant life. Sir Aurel Stein (18) estimates the size of this desert as about 900 miles long from east to west, and 300 miles in its broadest north-south

extent. It lies between long. 78°-93° E. and lat. 37°-41° N. The River Tarim, flowing from west to east, bounds the desert almost completely in the north; three roughly equidistant smaller rivers flow across from the southern edge of the desert towards the Tarim. Only two reach it now, though in the past less arid conditions have prevailed. The other rivers coming down from the mountains soon lose themselves in the desert.

Our best accounts of the Takla Makan are those of the Scandanavian explorer Sven Hedin, and the British archaeologist Sir Aurel Stein. Of the relevant Russian literature we have only seen a botanical paper by Popov (16). Stein's published maps (18) are excellent, including details of the vegetation and terrain. Hedin's journeys were probably more numerous and penetrated the heart of the desert, while Stein was chiefly concerned in visiting buried cities and ruins; we gather from Hedin (14) that it was scarcely worth while making a botanical collection because of the sparseness of plant life.

The Takla Makan depression is actually about 3,000 feet above sea level; this, combined with the high latitude (37°–41° N.), gives it far colder winters than any of the other deserts under consideration. Frosts certainly occur on winter nights in the Sahara, and in the Simpson Desert too, but the mean January (winter) temperature for the Sahara is everywhere above 50° F, as quoted by Kendrew (15). In Central Asia, the mean for January is much below freezing-point, small rivers are frozen all the winter, and the temperature rarely rises above freezing-point even at noon. Scanty records from Kashgar and Yarkand at the western end of the desert can guide us, together with observations made by Hedin on his journeys and quoted by Kendrew. He recorded a minimum of –25° F. in January in the middle of the Takla Makan, and on 2 January a maximum of only 8° F. At Tarim Jangiköl (alt. 2,890') at the eastern end, Hedin observed the following mean temperatures during his stay – February 17° F, March 40° F, April 55° F and May 69° F. The summer temperatures are not correspondingly lower. In the Sahara the difference between the mean summer and winter temperatures is of the order of 35° F.; at Kashgar it is 60° F., a tremendous range. The *daily* range, as far as records show, is in the neighbourhood of 30° F., as in the Sahara. The mean summer temperature for July is over 80° F. for Kashgar and Yarkand, compared with 90-100° F. for Saharan stations, and there are maxima of over 100° F., according to Kendrew (15).

Rain falls mainly in summer, but is augmented by melting winter snow; a mean annual precipitation of 3·5 inches has been recorded at Kashgar; in the heart of the desert it is probably less and very erratic. The mean relative humidity is generally low, and the high mountain barriers are responsible for excluding the rain-bearing winds. The figures just given (chiefly from Kendrew) for mean values in Central Asia are from *records of only 1-3 years.* (Refer also to Table I in the Appendix.)

There is no doubt that Hedin's journeys crossed the waterless desert dunes which are of so much interest to us. The most arduous of these journeys was in spring 1896 from the western end, 120 miles eastward to the first river flowing north (the Khotan-daria); on this occasion he lost two out of five men and seven out of eight camels (12). The chief difficulties were the sandstorms, the heat, the slowness of travel over the high, compound, steep sand-dunes or "dawans", sometimes as much as 200-300 feet high. Stein (18) later attempted a crossing in this region with a better prepared caravan, but he was forced to turn back; he vouches for the height of the sandridges, stating that the camels simply became exhausted crossing them. These dunes are practically parallel, and continuous enough to make detours around them out of the question. Some

of the dunes of the Sahara and Libyan Deserts are of this type and magnitude. In the dunes at the edge of the desert there were occasional shrivelled reeds and grass tussocks and solitary poplars; the last plants seen were tamarisks. In the desert itself on the fine, yellow, shifting sand of the dunes there was scarcely any vegetation. Once or twice plants were seen on these dunes, a solitary tamarisk (*Tamarix elongata*) here and there, reeds ("Kamish" *Lasiogrostis splendens*) in a hollow, and two or three isolated poplars. Eventually Hedin and the remnants of his party reached the river with its dense groves of tamarisks and poplars ("Tograks") in the sandy soil. The tamarisk out in the desert commonly grows as a shrub on top of a conical mound of sand held by its roots, and these "tamarisk cones" are mentioned and figured by both Stein and Hedin; the rare poplars and tamarisks found are often dead. Bagnold (2) describes tall tamarisk cones or "terabil" in the desert of southern Egypt, and these tamarisks seem to be the hardiest of all the vegetation. Along the River Tarim, the small "saline soil Saxaul" tree, *Haloxylon* (or *Anabasis*) *Ammodendron* (= *Arthrophytum Haloxylon*) occurs in place of tamarisks.

Hedin (13) also crossed the eastern end of the desert from north to south, in the cold of winter. The sand-dunes here are still parallel, but this time he travelled almost in the same direction, occasionally crossing the main dunes at an angle. There were smaller transverse ridges which he had to climb, dividing the valley bottoms into a series of depressions or "bayirs". The vegetation was as already described, rare patches of "Kamish" 8-9" high being seen.

Ephemerals are absent from the Takla Makan. Popov (16) states that the same scantiness of vegetation prevails in the Sahara, but that there is comparatively rich development of psammophytes in the deserts of Asia Media on the western side of the Pamirs, *i.e.*, in the Kara Kum and Kisil Kum. He supplies the following species names for the common names used by the explorers:

Desert poplar or tograk = *Populus euphratica* Oliv. and *P. pruinosa*;

Tamarisk = *Tamarix Pallasii, T. hispida, T. ramosissima* Ledeb. (forming cones), and others;

Reeds = *Lasiogrostis splendens* (Gramineae)—the Index Kewensis has '*Lasiagrostis*'.

Saline spots occur between the dunes, where the peripheral streams penetrate the desert underground, and here halophytes like *Lycium, Nitraria* and *Halostachys* are found. Other plants occurring, probably in the belt of riverine forest vegetation, are *Phragmites communis* (the common reed), *Glycyrrhiza inflata* and *Alhagi Kirgisorum*.

Popov says that the only psammophytes he occasionally found in Kashgaria were *Agriophyllum* and *Corispermum* (both Chenopodiaceae), which are annual sand halophytes.

In brief, then, the Takla Makan is characterised by very large sandridges almost as devoid of plants as is the Great Libyan Sand Sea. Its altitude (a plateau over 3,000' high) is equalled by only one of the other deserts in the present study, the Chihuahua (Mexico); and the latitude is also higher than all except the neighbouring Kara Kum Desert. These two factors give the Takla Makan colder winters than the other deserts, though its summers are still very hot; the annual temperature range is therefore greater than in most other deserts.

The few plants or their remains, seen only on rare occasions during a journey in the dunes, are poor, shrubby specimens of isolated *Tamarix* or *Populus*, and a small reed-like grass (*Lasiogrostis*). The tamarisks usually grow out of the top of a cone of sand held by their roots. The species names are quoted here just

as given by Hedin and Popov, and it is not considered necessary in the present study to go into the relationship of the species or their synonymy. No ephemeral plants occur, and the desert supports no human inhabitants. The Simpson Desert, though uninhabited, does not approach the Takla Makan in barrenness or in extent.

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C. RUB' AL KHALI

Southern Arabia contains the worst portion of the Arabian Sand Desert; it is known as the Rub' al Khali or Empty Quarter and is uninhabited. This remained one of the unexplored regions of the earth until quite recently, when it was crossed from south to north by Bertram Thomas (21) in 1931; a year later Philby (19) traversed the south-western part from east to west. Both these journeys were camel journeys of well over 300 miles, each through a varied desert terrain including high, bare parallel sand-dunes. Thomas, contrary to expectation, found water, but it was saline; Philby found none. From the accounts of these two experienced Arabian travellers are obtained our most adequate picture of the vegetation, and it is considered sufficiently representative. Both published good maps, especially Philby (19).

The plants seen were scarce, but were such an important part of the economy of the expeditions, providing the sole camel food and firewood, that they were continually mentioned in the narratives by their Arabic names. Some isolated vegetation was usually in sight, though often dead, and it was seldom necessary to make camp where none existed. Philby (20) states "from all accounts the Libyan Desert is worse off for vegetation than the Empty Quarter under the influence of a long drought". In the Libyan Desert fodder for the camels is carried with the caravan, but in Arabia the camels have only the forage they can find on the journey, and the desert crossings of Thomas and Philby were both made under these conditions, which would be quite impossible in the Libyan Desert. This gives a measure of aridity of the Rub' al Khali; the Arabs accompanying Philby often stated that, in their judgment, a given area looked as if it had had no rain for four or five years or longer, and this was very probably the case.

There is little doubt which are the important plants of the region—in Arabic—but their exact botanical identity is more uncertain. Thomas (22) gives a few botanical equivalents, and Philby (20) quite a long list in an appendix. On comparing these and weighing the evidence, the following information is obtained.

Hadh—probably *Salsola* sp. (Chenopodiaceae), according to Thomas (22). A saline, sage-coloured bush, the hardiest of all the desert plants. A good camel pasture, but too small for firewood. Widespread. Philby (20) gives

"Hadh" as *Cornulaca monocantha* Del. (Chenopodiaceae), on the authority of Rohlfs (8); the explanation may be that this name applies in North Africa where Rohlfs travelled.

Abal—*Calligonum* sp. (Polygonaceae). A large shrub often forming thickets. It also is very hardy and widespread. The wood is a good fuel, and large enough for making utensils and small structures.

These two appear the most important. Philby adds two more as being the further staple plants of the southern sands, *viz.:*

Alqua—*Dipterygium glaucum* Decne. (Cruciferae).

Andab—*Cyperus conglomeratus* Rotth. (Cyperaceae). A small sedge.

Then two slightly less hardy:

Birkan—*Fagonia glutinosa* Del. (Zygophyllaceae).

Zahr—*Tribulus* sp. A shrub, probably small. (Zygophyllaceae).

Under more favourable conditions at the edge of the desert occur several species of *Acacia* and grasses of the genus *Aristida*. There are also salt plains carrying samphires (*Arthrocnemum* spp. and related genera).

The plants showed distinct zonation, and the sands were usually better vegetated than the gravel plains. Philby (20) indicates that an ephemeral vegetation occurred after rains, but saw little of it; he just mentions Sa'dan (*Neurada* Rosaceae) and Halam (?) as tiny plants. His scientific "collections" ("plants" not specified) went to the British Museum, and some, at least, of his botanical information came from that institution. The writer could not discover where the plants named by Thomas (22) were determined.

The Rub' al Khali, then, is much less arid than the Libyan Desert or the Takla Makan, as evidenced by *some* vegetation (dead or alive) being always in sight; this vegetation is sufficient to sustain a few travelling camels, and to provide firewood. By contrast, camel fodder must be carried with the caravan in the Libyan Desert. Two shrubby plant species are the most important in the Desert—"Hadh" and "Abal" (probably *Salsola* sp. and *Calligonum* sp. respectively)—whilst a few others, including a sedge, a crucifer and some Zygophyllaceae also occur commonly in places; ephemerals grow after rain, and many other plants of less importance are present. The general use of Arabic common names by both Philby and Thomas would have made precise identifications difficult, unless good collections were also available. The Rub' al Khali is uninhabited for the most part. The dune regions with their vegetated valleys, and often slopes also, must bear some resemblance to those of the Simpson Desert, but apparently extensive areas devoid of vegetation do occur, particularly on the gravel plains.

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D. WESTERN SAHARA

The western part of the Sahara is better known than the Great Sand Sea, but it has been more difficult to obtain precise information about the flora of the ergs, as distinct from the flat, stony desert (hamada, serir and reg) and the wadis or dry watercourses; the wadis, especially, are the most favourable plant

habitat. The ergs cover only a small percentage of the total desert area, they are more accessible than the Libyan Erg and may contain sand-free passages a few miles wide, through which it is easy to travel.

Most of the knowledge of the Algerian Sahara is due to the military and scientific surveys of the French during the last 60-70 years, and the present inaccessibility of much of the relevant French literature has been a great disadvantage in this study. Among the more important sources of information available were Gautier (28), Engler (25) and Maire (30); the scientific reports of the Foureau-Lamy Expedition 1898-1900 were unfortunately among those not seen (27).

The Algerian ergs are not quite so large as the Great Sand Sea, nor so regular and unbroken; moreover, wells and pasturages may be present. The Edeyen Erg in Fezzan is a humid erg and habitable, with permanent lakes which are usually salt or brackish but in some cases fresh. The Great Oriental Erg and the Great Occidental Erg are drier, but the Occidental is furrowed by long lines of verdure which seem to follow underground wadis. Other ergs without obvious watercourses, like the Erg-er-Rawi and the Iguidi Erg, have plentiful underground water and associated pasturage.

The most inhospitable of the great Algerian ergs is the Esh-Shesh Erg, where wells are very few. From Gautier's remarks, it seems likely that there have been rare "good seasons" when the natives could find some grazing in it for their flocks; he stated that it is "accessible at a pinch". This was before the recent successful journeys of Bagnold and others into the Great Sand Sea, when that erg was still believed inaccessible. Monod, in 1937 (51), casually mentions that he crossed the El Shesh Erg when on a camel trip and gives a photograph of a mass of bare sand-dune summits, but no detailed account.

The area covered by the Oriental and the Occidental Ergs is, in each case, roughly 100 x 200 miles, and there are, of course, other relatively insignificant occurrences of dunes and unconsolidated sand in the West; but it is really difficult to obtain exact information about the vegetation of a given erg or dune-field. Generally speaking, sands are capable of better water relationships for plant roots than the various types of stony desert, but there must be available the minimum water requirement either as a pluvial or shallow subterranean supply.

It is enlightening to repeat the general impression of Gautier who has known the Sahara long and intimately. He says that the emphasis is on *the absence of plants*, and a "pasturage" is a relatively luxuriant area where there are tufts of plants at least fifty or sixty yards apart. This makes grazing "an extremely ambulatory exercise"; moreover, these pasturages are isolated from one another by a camel journey of many hours and often many days, even distances of the order of 100 miles. Local rain-storms cause the occasional appearance of short-lived ephemeral vegetation in normally bare regions; even so, the plants are very sparse. Apparently the root system of each must be able to exploit a great deal of soil, without competition from its neighbours, in order to obtain sufficient moisture.

This type of vegetation is "ashab" pasture and consists of a few different species, chiefly *Savignya longistyla* (Cruciferae), a rosette plant with purple-flowering stems from 4 to 18 inches high. In the Australian semi-desert areas, and probably the deserts also, ephemeral cruciferous plants of similar habit are very common after winter rains. Such plants were found in numbers and relished by the camels on Madigan's 1939 Simpson Desert Expedition, on the eastern margin of the desert where rain had fallen. We have not the long acquaintance with the Simpson Desert which is necessary to speak authoritatively about the ephemeral vegetation appearing only after rains; it is probable that these desert

rains are not so infrequent in Australia as they are in the Sahara. To return to the discussion of the ephemeral species of the Sahara, commonly accompanying *Savignya longistyla* and its allied species (see list below), there is another important crucifer, *Moricandia arvensis,* together with *Plantago ovata* and *Launea resedifolia.*

Tamarisk "cones", like those of the Takla-Makan Desert, hardly figure in descriptions of the dunes of the Sahara, though Bagnold (2) does describe a small group of high ones up to 50 feet called "terabil", *Tamarix mannifera,* in the flat sand-desert of southern Egypt. But several shrubs, including tamarisks, cause the accumulation of sand mounds in the western Sahara and still survive, *e.g., Nitraria, Limoniastrum* and *Aristida pungens.*

A short list has been appended of the important species present among the few plants of the Great Ergs; more cruciferous species might be included. In the mass they occasionally produce quite a floral spectacle, and most of them are favourite fodder plants; indeed, almost any plant provides fodder for camels. It is considered that the nomad tribes and their grazing camels have no small destructive effect on the vegetation of the Sahara (Chevalier).

One very helpful source for this list was Engler (25). Maire (30) is probably the best modern authority on the systematic botany of the Sahara and gives a very good outline of past work on the subject, as well as a flora of the region; but it was disappointing not to see the third part of his study, which he planned to contain an account of the vegetation from the geographical and ecological points of view.

Important Plants of the Western Sahara

On Dunes

Aristida pungens Desf. "drinn" (Gramineae). Widespread here and in the other Old World deserts. A grass of moderate size with long, shallow rhizomes, valued as a fodder and sand-binder. *A. plumosa* and other species also occur. Fig. Veg.-bilder, 6 Reihe, Heft iv, Taf. 24 (29).

Cornulaca monacantha Del. "had". (Chenopodiaceae.) A spreading shrub, favourite camel fodder.

Calligonum comosum L'Hér. "arisch". (Polygonaceae.) A broom-like switch-shrub or small tree; important as camel fodder. Also *C. azel* Maire. A noteworthy genus of Old World desert plants. Fig. Veg.-bilder, 20 Reihe, Heft i, Taf. 3 c, (29).

Savignya parviflora Webb (includes *S. aegyptiaca* and *S. longistyla.* Cruciferae). Polymorphic, short-lived, ephemeral herbs following rain; often the chief constituent of "ashab" pastures. Old World deserts; valued as camel fodder. Fig. Veg.-bilder, 20 Reihe, Heft i, Taf. 3 c. (29).

Moricandia arvensis DC (Cruciferae). Another important "ashab" ephemeral with the qualities of *Savignya.*

Malcolmia aegyptiaca Spreng. (Cruciferae). A widespread dune annual. Camel fodder.

Launea resedifolia O. Kuntze (Compositae). Perennial.

Plantago ovata (Plantaginaceae). A small herb of the "ashab".

Ephedra alata Dec. and other species (Gnetaceae). Mostly leafless switch bushes.

On Flatter Sandy Areas

Tamarix spp. Tamarisk (Tamaricaceae). Small trees, especially along wadis. Including *T. aphylla* Karst. "athel".

Limoniastrum guyonianum Coss. et Dur. (Plumbaginaceae). A shrub, often large and half-buried. Only the flowers acceptable as fodder.

Retama raetam Webb (Leguminosae). A leafless switch-shrub of the Old

World deserts. Only the flowers taken for fodder. Fig. Veg.-bilder, 6 Reihe, Heft iv, Taf. 23 (29).

Euphorbia guyoniana Boiss. et Reut. (Euphorbiaceae). A leafless switch shrub. Fig. Veg.-bilder *loc. cit.*

Matthiola livida DC (Cruciferae). Small, herbaceous sand ephemeral.

Traganum nudatum Del. (Chenopodiaceae). Shrub.

Nitraria retusa Asch. (= *N. tridentata* Zygophyllaceae). Shrub.

The dunes of the Western Sahara, then, are predominantly bare. The most noteworthy of the sparse vegetation are the rhizomatous, creeping grass *Aristida pungens,* various species of desert shrubs often broom-like in habit, and a selection of ephemerals (chiefly Cruciferae) of much importance after rain. These latter attract the nomad tribes in certain seasons.

The Simpson Desert is more densely and variously vegetated than the driest of the Saharan ergs, and its dunes do not attain the size of the largest in the Sahara. But in both cases the most widespread species is a grass, *Aristida* for the Sahara, and *Triodia* for the Simpson Desert. Further study of the ephemeral flora of the Simpson Desert is needed.

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E. THE SIMPSON DESERT

This desert lies almost in the centre of the Australian continent, in the three States of South Australia, Queensland and Northern Territory. It is a uniform area of continuous, parallel sandridges, running north-north-west and south-south-east and forms part of what is known as the Arunta Desert. Two or three water-courses enter it, and there are scattered shallow claypans occasionally filled by rain, but no permanent water except Anacoora Bore on the western margin, and some springs in the south (38). It has been explored and described recently in considerable detail, both from the air and on the ground, by Madigan (37, 38, 39, 40); it is therefore unnecessary to do more than mention the most important points here, but readers should consult these references and maps.

Madigan (38) reviewed journeys by himself and by earlier explorers around the margins of the desert, including his aerial reconnaissance in 1929. He was also the leader of the scientific expedition in 1939, which made the first ground crossing of the centre of the desert, and travelled some 200 miles, from west to east, by camel across the parallel dunes. The series of Scientific Reports of this expedition may be found in the Trans. Roy. Soc. S. Aust., where they were published between 1944 and 1948. (See especially the "Catalogue of Plants" (36) and "Soils and Vegetation" (35), Reports No. 7 and 8). Colson (34) in 1936, had crossed the southern part of the desert by camel, practically along the 26th parallel of latitude. No other crossings have been recorded, and the aboriginals, though nomadic, only visit the desert margins.

The dunes vary in height from about 30 feet to 100 feet above the level of the broad passages between them, and they are spaced on the average at four per mile but may be closer when small. They are strictly parallel and apparently unbroken for lengths up to 200 miles; the eastern slope is steeper than the western, and they consist of fine, red sand.

The upper slopes of the ridge are steep and usually bare and unconsolidated, with a sharp crest of live sand, while the lower slopes and inter-dune passages may be well vegetated with low, shrubby plants, chiefly spiny clumps of the grass "spinifex" (*Triodia Basedowii* E. Pritzel), so characteristic a genus of the Australian sandy deserts. Occasionally larger shrubs are also present, particularly several species of the genera *Acacia*, *Cassia* and *Crotalaria* (Leguminosae), *Grevillea* and *Hakea* (Proteaceae), and *Eremophila* (Myoporaceae). The last three genera are particularly Australian in their affinities, whilst *Acacia* is represented only by the peculiarly Australian phyllodineous section of the genus; other *Acacia* species are known as desert plants elsewhere. The shrubs *Sida* and *Hibiscus* (Malvaceae) should be added to the list, and also another shrubby grass important at times on the dunes, *viz.*, "Cane Grass", *Zygochloa paradoxa* (R. Br.) S. T. Blake 1941 (better known as *Spinifex paradoxus* (R. Br.) Benth.). The habitat differences between this species and *Triodia* have been explained by Crocker (35); briefly, *Zygochloa* is found on the unstable sand of the dune crests, which are not always bare, while *Triodia* is restricted to the lower slopes and corridors between the dunes.

The small, shrubby Chenopodiaceae, so common in the semi-deserts of Australia and other parts of the world, occur to some extent, but the family Leguminosae is more important among the dunes of the Simpson Desert. Eucalypts are rare and usually associated with the few watercourses which are defined, not by water, but by a line of verdure; only two species of *Eucalyptus* were found. These were, firstly, small trees of *E. coolabah* Blakely and Jacobs (formerly included with *E. microtheca* F. Muell.), "Desert Box", and secondly *E. pyrophora*, Benth., "Bloodwood", up to 12 m. high.

Some other small plants occurred in the desert, and they are listed in the present writer's Botanical Report (36) as "Plants found in the desert proper". It is believed that there must sometimes be present an ephemeral flora similar to that seen on the River Diamantina to the east after good rains, but it was not conspicuous in the winter of 1939 when Madigan's crossing was made, though he does record great mats of the succulent camel fodder "Munyeroo" (various Portulacaceae—in this case *Portulaca intraterranea* J. M. Black) at camp 11 around claypans of water near the middle of the desert. A few small ephemeral types of Cruciferae, Goodeniaceae and Compositae were found which might be more abundant in occasional good seasons. Compared with some, but not all, other important deserts of the world, the Simpson Desert is well covered with vegetation, though Madigan (39) found both camel food and firewood very scarce in

the centre of the desert. Between the dunes and on their lower slopes, the small shrubs (chiefly *Triodia*) are of the order of a few yards apart; many may be dead, but they do persist, holding the sand and forming a seed bed. *Triodia* is a perennial rhizomatous grass, often with a peripheral habit of growth, the centre of the bush dying and disintegrating, leaving a hollow ring. Many *Triodia* species, like, *T. Basedowii,* have pungent, hard, needle-like leaves of little use for grazing.

Few precise records of the climate of the Simpson Desert are to be had. However, together with the Lake Eyre region to the south, it forms the driest part of the Australian continent, receiving less than 5″ average annual rainfall; seven South Australian stations are below this figure. Evaporation is high, and the Meyer Ratio P/s.d. relating it to rainfall (refer to section on Thar Desert), does not exceed 2 for any month of the year (Prescott (41)). Other sources of information on the climate are the Commonwealth Climatological Atlas of Australia (42) and the reports of the 1939 Expedition, especially Madigan's geological report (40), and the meteorological log of his journey (39) from May to August. Crocker (35) gives data on the great variability of the rainfall, which has no particular seasonal periodicity.

Madigan's observations in the winter of 1939 may be summarised as follows:—"Weather brilliant three-quarters of the time, with warm days to frosty nights. *Temperature* range 23°-78° F., Min. temp. *at grass* 23° F., Mean min. at grass 38·5 F. Average max. temp. 70° F. *Rain,* six rainy periods in ten weeks, mostly very light. In 5 days, 1½″ fell in the desert; and in 6 days, 2″ fell at the Mulligan—this was exceptionally wet. *Wind* did not exceed 20 miles per hour in the desert."

From Commonwealth sources—summer temperatures up to 110° F. or over, with nights at 60°-70° F. *Rainfall*—never as low as zero, but varies from less than 2″ up to 12″; and droughts of less than 2″ may last for three or four years. At Charlotte Waters, on the western margin, the total annual amounts in inches from 1895-1915 were as follows:—

10·40, 2·84, *1·16* 5·23, 2·74, 3·79, 3·22, 2·40, 9·67, 3·78, 3·94
2·11, 5·43, 12·31, 2·75, 6·81, 4·58, 2·73, 4·37, 9·06, *1·43.*

The lowest recorded is 0·43 at Kanawava on the Cooper in 1896.
Some further data supplied by Madigan are quoted below.

SIMPSON DESERT CLIMATE — FROM CLIMATOLOGICAL ATLAS OF AUSTRALIA (W. S. Watt).

Temperature	Jan.	Feb.	Mar.	Ap.	May	Jun.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Mean daily max.	100	100	95	86	76	70	70	75	82	90	96	99
				Mean max. for year 86° F.								
Mean daily min.	73	73	67	58	50	45	43	46	52	60	67	71
				Mean min. for year 59° F.								
Mean daily - -	86	86	81	72	63	57	56	60	68	75	81	86
				Mean annual temp. 73° F.								
Relative Humidity:												
9 a.m.	31			35?			45			28 (<30)		
				Mean rel. hum. at 9 a.m. for year 38? (<40)								
3 p.m.	<20			25			30			<20		
				Mean rel. hum. at 3 p.m. for year 22.								
Rainfall (inches)	¾″	¾	½	<½	<½	¼	<⅓	<¼	<½	<⅓	<½	¾
				Mean annual rainfall <5″								

The Simpson Desert lies over the Great Artesian Basin, whose waters reach the surface at natural mound springs and bores outside the desert margins; permanent surface water is absent. It has been briefly compared with other important deserts in turn, at the end of each section of this study and, after careful consideration, of the vegetation particularly, has been placed fifth out of eight in order of aridity. The Libyan Desert and the Takla Makan are without doubt much more barren of plant covering. The sands of the Rub' al Khali are probably more bare than those of the Simpson Desert, and it is also believed that rainless periods of one or more years occur there. In the Western Sahara some of the ergs may support less vegetation than the Rub' al Khali, while some others are more humid than the Simpson Desert. The Kara Kum often exhibits complete vegetative cover of the dunes with groves of small trees, perhaps comparable to the Australian "mallee" formation; temporary grazing takes place there, and the rainfall is about the same as in the Simpson Desert, but we believe that more vegetation and better soil-water relationships exist in the Kara Kum. It has been shown in Section H that the Simpson Desert is more arid than the Thar in India, where the ratio of rainfall to evaporation is higher, with sparse settlement and grazing flocks.

Some uncertainty is felt about the comparison of the Mexican Chihuahua Desert with others; the average annual rainfall does not exceed 8" and vegetation is very scarce (the last could not be said of the Simpson Desert), but whatever the technical aridity of this desert, conditions are ameliorated by its smaller size. It has been rated less arid than the Simpson Desert.

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F. THE KARA KUM DESERT

The Kara Kum Desert comprises most of the province of Turkmenistan in western Turkestan, to the east of the Caspian Sea. The Amu Darya (or Oxus River) flows down from the Pamirs, in a north-westerly direction into the Aral Sea, crossing the desert; the portion on the south-west of it is the Kara Kum and that on the north-east is the Kisil Kum. The sand desert is here the most extensive formation.

Detailed accounts are available for the south-eastern Kara Kum, emanating largely from the Russian Sand Research Station at Repetek established in 1912;

this south-eastern portion represents about one-sixth of the total area of the Transcaspian Kara Kum. It is a varied terrain and probably a fair sample of the whole Aral-Caspian desert region of Asia Media.

The Central Asiatic Railway runs from Krasnovodsk on the Caspian, skirts the south of the desert and eventually turns north-east across it beyond Ashabad, thence by way of the oasis of Merv, Repetek, Bokhara, Samarkand and Tashkent, crossing the Oxus about 50 miles beyond Repetek. The area now to be described is diamond-shaped, with Merv on the western corner and the Oxus forming the north-eastern side; Repetek (lat. 38° 5′ N., long. 63° E.) is near the north point of the diamond, which is bounded by railways on the west, extending north-east and south-east from Merv; Afghanistan abuts the south-east side, and the diamond is about 200 miles across.

These deserts of Western Turkestan are also known as the deserts of Turan and provide an interesting comparison with the desert of the Tarim Basin just over the Pamirs in Eastern Turkestan. The emergent feature is the greater richness of vegetation in the Russian deserts of the west; this was touched upon above in the discussion of the Takla Makan Desert, where the mountain barriers almost surrounding the latter are mentioned as effective means of isolation from plant immigrants (47). However, the psammophyte flora of Turan contains a striking number of endemic species, and even genera; Popov (47) puts this down to "an extensive process of species formation in post-Miocene times," which did not occur in the Tarim Basin or in the Sahara. He mentions especially the absence from the Takla Makan of a hardy psammophyte pioneer grass like *Aristida pennata* var. *Karelini*, which is endemic in the Caspian-Aral deserts (the Saharan equivalent is *Aristida pungens*).

The reasons for this extensive process of species formation need not be discussed here, except insofar as they may be connected with the environment at present provided for plant life. The plants of the Kara Kum sand deserts show fairly rapid colonization of moving sand and succession of different types of vegetation, eventually stabilising the dunes. The question is whether these plants are exceptionally well fitted for an arid sandy environment or whether there is also some ameliorating influence in the environment itself. The work of Orlov (45) at Repetek, though not denying the first alternative, lends support to the second; his studies in the moisture changes of the sand confirm the presence of a special sub-superficial horizon, roughly 1 m. down, of increased moisture content and with drier sand above and below it. The annual rainfall is less than 4″, and he attempts to explain the phenomenon by the faculty of those particular sands to absorb condensed water vapour from the air, upon and in the surface layers, at night.

Human occupation in the eastern Kara Kum is restricted to the oases and narrow river valleys. Shepherds and their flocks sometimes make temporary excursions into the desert, obtaining water from wells which easily fall in because of the sandy soil. Repetek is purely a railroad settlement and receives its household water by rail. It is in the midst of unstabilized barchan sands with scanty vegetation. The Russian interest in this area is not purely scientific; parts of it have economic possibilities for sheep and cattle-raising, with problems of exploitation of the natural fodder very familiar to Australians; there is also the question of the control of the moving barchan sands by vegetation near the settled areas; the saxaul forests, too, must be preserved for fuel; and finally there are ambitious projects for irrigation close to the sands.

Extensive exploratory journeys in the south-eastern Kara Kum were made by Doubiansky (43). We are much indebted to him for his account, which is very full and most helpful botanically.

These deserts are mainly within 1,000 feet of sea-level, and the extreme and protracted winter cold of the Takla Makan at 3,000 feet is not to be expected. The Turan deserts are very hot in summer, possibly not quite so hot as the Takla Makan; some figures may be given, but should be accepted with caution as representing mainly short-term records; compare these also with those already given for the Takla Makan. No evaporation or atmospheric humidity data seem to be available, but the air is stated to be very dry, and the great diurnal range of temperature common to deserts is normally about 20° C. (*i.e.*, 36° F.), according to Doubiansky, with higher maxima; this figure is about the value given for the Takla Makan and Sahara.

The daily minimum temperatures in winter fall as low as $-20°$ C. ($-4°$ F.) at 4 a.m., but they are not sustained as in the Takla Makan, and any snow which falls usually thaws during the day, or rarely lasts a week or two (Seifriz (48)). Doubiansky states that the average *winter* air temperature is never below freezing point at Repetek (Seifriz states that the average for January alone is $-7{\cdot}7°$ C. ($=18°$ F.), which is probably not a contradiction of Doubiansky's statement), and the average for summer is $> 30°$ C. (86° F.).

The annual rainfall has two maxima, one in spring and a lesser one in autumn; there are no rains in summer for at least four months, sometimes eight. Much of the Turan sand-dune desert has an annual rainfall of less than 4". Some figures are set out in the Appendix (Table I) giving rainfall and temperature values.

The Sands and the Vegetation

According to Doubiansky (43), the portion of the south-eastern Kara Kum mapped by him represents about one-sixth of the total trans-Caspian Kara Kum and is made up as follows:—

(1) One sixth consists of a *barchan range* of bare sand bordering the River Oxus in a band 10-50 km. wide (6-31 miles), covering an area of about 9,000 sq. km. ($=3{,}420$ sq. miles). Repetek seems to be in this region.

(2) One-sixth consists of *sandy hills carrying a growth* of shrubby psammophytes and saxaul forests.

(3) One-quarter consists of *sandy ridges richly covered* with vegetation.

The rest of the area comprises sandy-clayey plains and foothills and does not concern us here; the regions just set out will now be described in more detail.

(1) The *barchan range* is made up of parallel "barchan rows" running roughly north-east and south-west, generally at an angle to the river. The sand is probably derived mainly from river valley alluvium and forms at once into these barchan rows, hardly passing at all through the stage of the component single crescentic barchans. The barchan rows are not very high, say 3-10 metres or even 18 metres (60 feet), they have vertically sinuous crests and are up to several hundred metres long, with a basal width of 100 metres or less and a valley of the same width between.

Work during four years at Repetek has shown that the crests of the barchan rows have a seasonal movement transverse to their length; in summer they move south-east 15-20 metres and in winter back again under the influence of the prevailing winds (which are not necessarily at right angles to the barchan row); the net change of position, if any, is very small; the side on which the steep or slip-slope occurs is thus regularly reversed. Plants establish themselves on the more stable lower slopes and hollows between the rows, where a sparse growth of the hardy endemic pioneer grass *Aristida pennata* Trin. var. *Karelini* Trin. et

Rupr. "seline" is almost the sole species found; it is a coarse grass forming shrubs three feet high, of some fodder value, and able to survive much burying and uncovering by the sand. Doubiansky estimates that it covers at least 10% of the barchan sand area. This is the psammophyte that Popov (47) expected in vain to see, above all others, in the Takla Makan. (C.f. *Triodia Basedowii*, Simpson Desert.)

In the hollows between the barchans occur the annual sand halophytes:—*Agriophyllum latifolium* F. et M. (Chenopodiaceae); *Corispermum hyssopifolium* L. (Chenopodiaceae); *Horaninowia ulicina* F. et M. (Chenopodiaceae), a small spiny shrub; and *Smirnowia turkestana* Bge. (Leguminosae), a shrub occasionally seen here.

(2) Under suitable conditions, the barchans are stabilised into *sandhills* by pioneer shrubs, many of them switch bushes. First in importance is the *Aristida* sp. mentioned, then *Calligonum* spp. (*C. Caput Medusae*, Schrenk, *C. arborescens* Litw., *C. elatum* Litw.). These are all leafless Polygonaceae, some of them endemic. Further species are also important:—*Ammodendron Conollyi* Bge. (Leguminosae), a shrub or tree; the whole genus consists of psammophytes endemic to Turkestan; *Acacia* sp. (Leguminosae), arborescent; *Eremosparton flaccidum* Litw. (Leguminosae), a leafless tree or shrub, the whole genus is endemic to the sands of Turkestan.

It is not to be supposed that these first-line pioneers suffer no casualties, for the colonisation of these wind-swept sands is often full of setbacks. Less resistant plants following on these are:—
Calligonum eriopodum Bge. (Polygonaceae), arborescent; *Astragalus ammodendron* (Leguminosae), semi-shrub; *Aristida pennata* Trin. var. *minor* Litw. (Gramineae); *Salsola Richteri* Kar. (Chenopodiaceae), arborescent; *Carex physodes* M. B. (Cyperaceae), a low endemic sand-sedge forming a thin cover between the bushes, it is the most widespread plant in the sands of Turkmenistan and important for forage; as it covers the sand, the earliest pioneers disappear entirely; this plant does not survive in drifting sand.

The third stage follows in which, among other species, *Calligonum setosum* Litw. (Polygonaceae) is the most widespread shrub, and *Arthrophytum arborescens* Litw. the Sand Saxaul (Chenopodiaceae), forming tall, leafless clumps, is the most important.

Under the influence of humus from this cover of vegetation, the sand becomes consolidated and saline in the surface layers and the climax forest community of these sands is able to develop. This is *Arthrophytum Haloxylon* Litw. (*Haloxylon Ammodendron* Chenopodiaceae) or Saline Soil Saxaul. It develops first in the hollows between the sand ridges as an almost pure community of open structure.

The Saline Soil Saxaul is a small tree 12′-20′ high, greatly valued in Turkestan as a source of fuel. It grows nowhere else in the world and is really a very remarkable forest formation, capable of developing in pure sandy or salty deserts with an annual rainfall of only 4 inches or even less. The forest occupies small and scattered areas and has, of course, been over-exploited in parts, especially along the Middle Asiatic Railroad. Regeneration from seed is not very easy; a denuded Saxaul forest probably reverts to bare barchan sands. *Ephedra* spp. (Gnetaceae) are small shrubs characteristic of the pioneer stage, but not abundant.

Studies by Petrov (quoted by Seifriz (48)) of the root systems of Kara Kum psammophytes, establish the fact that the hardiest of the pioneers of moving sands, *Aristida, Eremosparton* and *Ammodendron*, exploit only the "sub-superficial" moisture horizon with an extensive horizontal spread of roots in the layer of sand 40-150 cm. below the surface; there is drier sand both above and below

this. The plants following these in the succession soon develop roots which also tap the ground-water, found at a fairly constant depth of 3-4 metres, in the barchan valleys; this is unusually shallow for a desert and probably goes far to explain the relative fertility of the Kara Kum sands. Besides the important plants named, there is quite a rich ephemeral spring vegetation (Seifriz (48)).

(3) The most widespread formation in the South-eastern Kara Kum is that of the *sandy ridges covered with vegetation.* They are up to 50 m. high (170′) and 3-5 km. long (2-3 miles), and run chiefly north and south or north-north-east and south-south-west; the eastern slope is the steeper and there are broad-bottomed valleys between. Secondary bare areas are to be found on the tops of these ridges, here and there.

It seems unlikely that these ridges are barchan rows of the type just described, merely stabilised by vegetation; they are on a much larger scale and probably have a different history.

Only on the occasional bare areas are found a few of the more hardy psammophytes mentioned earlier. The steeper slopes have the shrubs *Calligonum* and *Astragalus* with an herbaceous cover of *Carex physodes.* On the lower slopes and valley bottoms these die out at the invasion of a cover of annual grasses which may yield a large amount of forage in the occasional good seasons, and at other times leave the ground bare. It seems better, however, to have the more reliable growth of sand-sedge (*Carex physodes*), even though it is a poorer fodder, with some of the psammophyte shrubs to yield firewood. This can be ensured by checking the natural plant succession by controlled sheep pasturing.

It will be remembered that trees or stunted trees of the genera *Tamarix* and *Populus* comprise the bulk of the extremely sparse vegetation of the Takla Makan Desert; so far these have not been mentioned as important in the Kara Kum. However, the same species do occur naturally along the Oxus and elsewhere, and they are also used for planting to control the moving barchan sands beside the settled valley of the Oxus. Paulsen (46) mentions tamarisks on knolls in the "Hummock Desert".

Our final impression of the south-eastern Kara Kum is that it is one of the more fertile deserts with a richly developed endemic flora (22% of the species, according to Paulsen) of well-adapted psammophytes, and this is linked with very favourable soil-water relationships established in spite of low rainfall. We consider it better vegetated and more fertile than the Simpson Desert.

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G. THE CHIHUAHUA DESERT

The western and south-western part of North America contains the most important of the deserts of that continent, *viz.*, the Great Basin Desert, the Mohave Desert, the Sonora Desert and the Chihuahua Desert. The last, which lies chiefly in the central plateau of Mexico and the State of New Mexico, will be our chief concern, because it has a sandy region about 100 miles square (53), some 30 miles south of El Paso on the border. This includes an area of parallel dunes locally called Los Medanos, which run north-west and south-east for about 20 miles. They are white or yellow in colour and nearly bare of vegetation. There is a road through them, which often becomes entirely obliterated by blown sand, and also a railroad traversing dunes about 40 feet high.

The sand and dunes surround some large lake beds belonging to an internal drainage system in northern-most Chihuahua, and from these they are probably derived; the dunes are active and largely unstabilized. They are from 50 to 300 feet high (53), and, as with most such inhospitable places, are not very well known to botanists.

Shreve (53) reports that the vegetation is mainly shrubby, sparse and irregular, giving as the characteristic plants the following:—

Poliomintha incana (Labiatae), a woody bush;

Yucca elata (= *Y. radiosa*, Liliaceae), a plant with a large sand-binding root-system and a stem which lengthens on silting up;

Prosopis chilensis (= *P. juliflora*, Leguminosae); Mesquite or Algaroba Bean. A widespread shrub or tree in southern U.S.A.

Artemisia filifolia (Compositae); Sand sage brush, a small shrub;

Dolea scoparia (Leguminosae); and

Hymenoclea monogyra (Compositae), shrub.

To these, MacDougal (52) adds—a shrubby *Senecio* (Compositae), *Chrysothamnus* (Compositae); two frequently occurring perennial grasses *Sporobolus cryptandrus* and an *Andropogon;* and the remnants of annual plants. He stresses the dominance of *Poliomintha*.

He states, also, that the valley bottom near Samalayuca, an oasis on the railway in the dunes 30 miles south of El Paso, has vegetation typical of the mesquite plains, *viz.*, *Prosopis juliflora* Mesquite Tree (Leguminosae); *Zizyphus* (Rhamnaceae); *Koeberlinia spinosa* (Capparidaceae); *Atriplex canescens* (Chenopodiaceae) and an annual *Croton* (Euphorbiaceae). The valley bottom referred to is probably not an inter-dune hollow. Chemical analyses of the dune-sand are also given.

It is not easy to find meteorological records for this precise area; annual rainfall figures for the various stations in the neighbouring desert range from just under 3″ to about 16″ per annum, and the annual evaporation values quoted by MacDougal (52) are many times greater. El Paso (alt. 3,760′), on the Rio Grande, is the nearest available station and has a rainfall of 9·5″ with the maximum in July; July is also the hottest month with a mean temperature of 80·5° F., January is the coldest month with a mean of 44° F.; the means of several yearly extremes are 104° F. and 12° F.; the daily range of temperature is quite high and has a value between 30·5 and 38·5° F. for the whole year, as is usual in deserts.

Shreve (54) has published a map showing the mean annual rainfall of Northern Mexico, in which the dune area under consideration falls into the zone receiving 0-200 mm. (0-8″). Judging from his tables showing the length of rainless periods experienced at the recording stations, some of which are in neigh-

bouring deserts, it must be quite unlikely that so much as a year passes without rain; this is in strong contrast to the Sahara and Libyan Deserts.

It is difficult to assess the degree of aridity of this desert in comparison with others, since its much smaller size lessens its importance. The sandridge portions of it may be less vegetated than most of the Kara Kum or the Simpson Desert, but it seems more correct to rate it less arid than these in the present state of our knowledge. In comparison with the Thar Desert in India, the Chihuahua, we believe, is more barren of plants, though the Thar is larger and more important. The criterion of human habitation as a measure of aridity may break down where relatively small areas like the Chihuahua are concerned, because their lack of development is not such a serious economic loss to the country as the neglect of larger areas would be.

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H. THE THAR DESERT

This region is described by Blanford (58) as that part of the great Indian Desert which has dense areas of parallel sand-ridges. The great Indian Desert itself, he states, is by far the most important accumulation of blown sand in India; it is situated in Sind and Rajputana and extends roughly from Karachi and the Rann of Cutch, north-east almost as far as Delhi, and is bounded on the north-west by the alluvium of the River Indus and its tributaries, and on the south-east by the Aravalli Hills.

The sandridges of the Thar form two important groups converging on the Rann of Cutch, one group extending due north from the Rann and having the Indus on its west and north, the other running north-east from the Rann with the River Luni on its south-east side. The latter area of sandridges consists of smaller and more irregular dunes. The dunes near the Rann are highest of all and are quoted by Blanford as having an elevation of 400-500′; the areas covered by dunes are of the order of 50 miles wide. The other parts of the Indian Desert have more isolated and irregular sandhills. As these long, parallel dunes of the Thar Desert are considered by Madigan (37) to be closely comparable to those of the Simpson Desert, though of lesser extent, it seems worth while to examine their vegetation.

The fullest account available was that of Blatter and Hallberg (55), who made a journey in the eastern Thar in October-November 1917, through the lesser of the two main sandridge areas. Their route formed a square, each side measuring about 100 miles. At the corners of this square were Jodhpur, Bap (just north of Phalodi), Jaisalmer and Barmer. There is a railway between Barmer, Jodhpur and Phalodi. The other part of the journey was made on camels.

A vegetation map of India has been prepared by Schokalsky (59) in 1932, in connection with her work on the soils of that country and her soil map. According to this, the route of Blatter and Hallberg lay mostly in the types designated by her as (1) *"Arid sandy desert and barren land,"* and (2) *"sandy desert with thorn"*; about one-quarter of the route lay in type (3) *"steppe desert with thorn"*. The "thorn" formation is not described in detail. We may assume, then, that Blatter and Hallberg really travelled through some of the most arid sandy country in the Thar Desert and that the vegetation they describe is relevant to the present study.

Vaughan Cornish (56) states that the region is well surveyed and that all the plans show these parallel sandridges. Madigan (37) reproduces a similar survey map with parallel ridges for country adjacent to the Simpson Desert. It seems unlikely that country as arid and uninhabited as the Simpson Desert would come within routine land survey work, and it is inferred that the Thar is a less inhospitable region than the Simpson Desert. Meteorological data for comparison are scanty, but it is clear that though the Thar Desert is without streams and has a most erratic rainfall, it still supports sparse settlement with scattered villages and numerous flocks and herds of camels, goats, cattle and sheep; there are also shrubs and bushes and occasional small trees subject to grazing. The vegetation, therefore, is probably more comparable with the Australian semi-desert areas which also have parallel sand-dunes in a milder way.

Blatter and Hallberg discuss the climatic data available in the area visited by them. They quote a year with no rain at all recorded for certain stations, and another occasion on which 10″ fell in one day at Jodhpur; 1917 (the year of their visit) was unusually wet with totals ranging from 20-40″ in different localities, as compared with average values, calculated over 40 years, of 7-13″. The mean number of rainy days is from 13-18 per annum; 1917, of course, was much higher. The wet season is during the summer monsoon from June to September inclusive; the cold season is from November to March and characterised by extreme temperature variations, often falling below freezing point at night. The relative humidity is always low, and very hot and violent winds with sandstorms are frequent in April, May and June.

In Australia, the Simpson Desert is in an area of the continent within the 5″ annual isohyet (42) and with a high variability. Prescott (41), in his analysis of the climates of the Australian deserts, uses the Meyer ratio—P/s.d.—, calculated month by month, to define areas of successive aridity; the area having lowest values coincides with the Simpson Desert region where it is between 1 and 2 for the months of greatest value, never higher; in the major part of the surrounding truly desert region this monthly value rises to a maximum of 4 or 5.

The monthly values for P/s.d., calculated for Pachbhadra from data given by Blatter and Hallberg in connection with their journey in the Thar Desert, are as follows:—

Jan.	0·84	May	0·58	Sept.	4·48
Feb.	0·35	June	1·71	Oct.	0·08
March	0·17	July	*8·08*	Nov.	0·12
April	0·09	Aug.	*10·03*	Dec.	0·29

Note the high values for July and August.

Hosking (57) has prepared a map showing the values for the Meyer ratio (calculated from mean *annual* precipitation and mean *annual* saturation deficit) over the whole of India. The lowest values occurred over the Indian Desert and here he analysed a small area in more detail,[2] using the monthly instead of

[2] This more detailed map is unpublished, and quoted by kind permission of the author.

annual values for the Meyer ratio, as we have done, and drawing the isologs of the maximum monthly value occurring in the year, as Prescott has done for Australia. Hosking found that there was not a close correlation between the lowest values of the Meyer ratio and the distribution of the sand-dunes of the Thar Desert. There was an area below 2, more than 100 miles across, on the right bank of the Indus around Sukkor, whereas the Thar Desert lies on the left bank of this river. The values for the desert itself are from 3 to 6 + (Hosking) and as high as 10 (our own data, table above). As far as this criterion of desert climate goes, not more than the north-western half of the Thar is comparable with the desert regions covering most of the centre of Australia, and *none of it is quite so arid as the Simpson Desert,* unless the steppe west of Sukkor be included in its borders.

In view of this, comparison of the vegetation of the two sandridge areas loses some of its interest. However, a short description of the plants recorded by Blatter and Hallberg will be given here, and it becomes significant to note that their visit took place in October-November just after the usual period of heavy rains, and in a phenomenally wet season. They may therefore have seen the vegetation in a better state than usual (as did Madigan on the Diamantina), though no ephemerals were found and few annuals. With this in mind, an attempt will be made to extract from their results what plants actually grow on the sandhills of the Thar Desert. It appears that whenever the dunes are sufficiently stabilized, they can support quite a dense cover of vegetation. Most of the plants are deep-rooted shrubby perennials and are listed below.

After this examination, one is drawn to the conclusion that the environment of the south-eastern Thar Desert, at least, is by no means as arid as that of the Simpson Desert.

Plants Growing on the Dunes of the Thar Desert

(ref. 55)

x = widespread and important plants

x *Calotropis procera* R. Br. (Asclepiadaceae)—One of the earliest and most hardy colonisers of bare dune slopes; a quick-growing course shrub of catholic taste. Dunes may have a pure society of this plant.

x *Indigofera argentea* Burm. (Leguminosae)—Another typical dune pioneer often forming a pure society; it has a low crown of horizontal branches near the sand surface.

x *Crotalaria burhia* Hamilt. (Leguminosae)—The most abundant plant of the region, following close after the above two pioneers and replacing them; shrubby.

x *Leptadenia spartium* Wight (Asclepiadaceae)—A common dune shrub, usually a secondary arrival and rarely dominant.

x *Aerua pseudo-tomentosa* Blatt. and Hallb., and *A. tomentosa* Forsk. (Amarantaceae). These grey-white shrubs grow with *Crotalaria* at the edge of dunes and on sandy flats, which probably recall the Australian bluebush and saltbush plains in appearance.

x *Calligonum polygonoides* L. (Polygonaceae)—A large bush up to 5-6′ diameter, occurring chiefly on sand, but adaptable, showing a preference for dune crests which it may monopolise; roots often exposed.

x *Cyperus arenarius* Retz. (Cyperaceae)—Establishes itself in thick patches on the lee slope of dunes; this and other Cyperaceae are the most effective sand stabilisers in the region, on account of their creeping rhizomes.

x *Panicum turgidum* Forsk. (Gramineae)—An early coloniser with the shrubs.

Citrullus colocynthis Schrad. (Cucurbitaceae)—An early coloniser.
Farsetia jacquemontii Hook. f. et Th. (Cruciferae)—An early coloniser.
Pennisetum cenchroides Rich. (Gramineae)—A common sand and dune grass.
Eleusine sp. (Gramineae)—An early coloniser.
Capparis decidua Pax (Capparidaceae)—Occurs on flat sand with *Aerua;* a shrub or tree.
Among the commonest sand grasses were *Eragrostis tremula* Hochst., *E. ciliaris* Link. and other species; *Cenchrus catharticus* Del. and *Pennisetum prieurii* Kunth.
Breweria latifolia Benth. (Convolvulaceae)—A typical sand shrub.
Small *Convolvulus* spp. and *Polygala* spp. occur between the bushes.

The following may be mentioned among other plants occurring:—

Lycium barbarum L. (Solanaceae)—A shrub at times common on dunes.
Boerhavia diffusa L. (Nyctaginaceae)—A small trailing plant also throughout Australia.
Aristida, two species (Gramineae).
Haloxylon salicornicum Bunge (Chenopodiaceae)—Abundant locally, but prefers gravel; grows in sand-holding clumps.
Cassia obovata Collad. (Leguminosae)—Locally abundant on dunes.
Zizyphus rotundifolia Lam. (Rhamnaceae)—A prickly shrub or tree.
Cistanche tubulosa Wight (Orobanchaceae)—A root-parasite growing on various shrubs.
Tamarix articulata Vahl. (Tamaricaceae)—Collected, but apparently not common. (Synonyms *T. aphylla*, L., *T. orientalis*, Forsk., *T. articulata* Vahl.). This is the evergreen Athel Tree now widely used for dry, sandy areas in South Australia.

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SUMMARY

In order to assess the comparative aridity of the Simpson Desert in relation to other important sand-ridge deserts of the world, a study has been made of the vegetation of seven of them. It is considered that vegetation is the best climatic index available for regions where quantitative meteorological data are generally so few. The results of this study are briefly summarised in the appended Tables I, II, III, and IV, in which the deserts in question have been placed in order of aridity. Some doubt is still felt about the correct position of the Mexican

Chihuahua Desert in this list; it may be more arid than the Thar, but it is certainly less important on account of its much smaller size. Approximate geographical position, altitude, and size of the deserts are given in Table II. The degree of plant cover, the dominants and the state of habitation are summarised in Table III. Table IV lists noteworthy genera in each desert.

It is clear that the first four deserts in this list form a very arid and barren group, and that the last four, including the Simpson Desert, are much better covered; some of them, like the Thar, have much of the character of a steppe. A comparative study of the availability of underground water would go far to explain this; it is also certain that some of these deserts enjoy a far more regular rainfall than others in which dry periods of a few years are the rule. The stretches of absolutely bare dunes in the Great Libyan Erg and the Takla Makan seem to be unique, even among the deserts of the Old World.

The plants actually present are mainly perennial shrubs and psammophytes, occasionally reinforced by ephemerals; the *Tamarix* and *Populus* of the Takla Makan are tree types of stunted growth, while the Kara Kum achieves regular forests of the small saxaul trees. Each of the regions shows considerable individuality in its flora, particularly the Mexican and Australian areas, as one might expect; there is a much closer degree of similarity between the more contiguous deserts of the Old World. Attention must be drawn to the importance of a shrubby grass in three of the deserts—*Triodia* in the Simpson Desert, and two species of *Aristida*, respectively, in the Western Sahara and Kara Kum. For a detailed account of the vegetation of the Simpson Desert, the paper in this series by R. L. Crocker (35) should be consulted, as well as the list of species collected on Madigan's expedition as reported upon by the writer (36).

As far as this study is concerned, special habitats like wadis and watercourses have not been considered. As they have a denser and often distinctive vegetation, attention has been focused on the dune areas.

Where possible, meteorological data have been included, but they have proved quite inadequate for comparative purposes, except in the case of the Thar Desert.

It is interesting to note that before 1925 the Libyan Erg, the Rub' al Khali and the Simpson Desert were practically unexplored. Our knowledge of the Takla Makan and much of the Western Sahara goes back only to about 1860, though the primitive method of camel travel was used in all the recent surface explorations, except in the Libyan Erg where Bagnold and Clayton used motor cars.

In conclusion, it may be inferred that the Simpson Desert, the worst of the Australian sandridge deserts, compares in size with the most important dune areas of the earth and, though arid, is exceeded in this respect by the Libyan Erg, Takla Makan, Rub' al Khali and Western Sahara, but *not* by the Kara Kum, Chihuahua and Thar deserts.

ACKNOWLEDGMENT

A debt is due to the late Dr. C. T. Madigan, who read the almost completed paper before his death and made important suggestions for improvement. The section on the Simpson Desert was not completed at that time and he contributed much meteorological data for it.

TABLE I — APPENDIX

SOME CLIMATIC DATA FOR THE KARA KUM AND TAKLA MAKAN DESERTS

Station and source of data	Situation	Altitude above sea level in ft.	Mean temperature for January	Mean temperature for July	Mean annual rainfall
Petro-Alexandrovsk (Kendrew) Nukus (Köppen)	On the River Oxus within 200 miles of the Aral Sea	295′ 230′	23°F 21°F (−5·9°C) Av. min. −15°F (−26°C)	83°F 80°F (26·4°C) Av. max. 104°F (40°C)	2·4″ max. in April 3·5″ (9 cm.) max. in April
Kerki (Köppen)	On the River Oxus 150 miles S.E. of Repetek	800′	35°F (1·8°C)	84°F (29·0°C)	6·2″ (16 cm.) max. in March
Repetek (Doubiansky) Lat. 38.5°N Long. 63°E	In centre of sand-dune desert 50 miles South of the Oxus. U.S.S.R, Sand Research Station	1,000′	18°F (−7·7°C) Av. min. −6°F (−22·5°C) Jan. 1927 (Seifriz)	Say 86°F (30°C) Observed max. 122°F (50°C)	3·7″ (9·39 cm.) Range— 2·4—17·0 cm. 5 years' records
			Records short		
Merv (Kendrew)	An oasis in the sand-dune desert 100 miles south-west of Repetek	755′	—	—	7·5″ max. in March
Aschabad (Köppen)	200 miles west of Merv on the edge of the desert	730′	33°F (0·5°C)	86°F (30°C)	8·2″ (21 cm.) max. in March
Kashgar (Kendrew) Yarkand (Kendrew)	West edge of Takla Makan in Tarim Basin	4,255′ 4,120′	22°F 2-3 years' records only 21°F min. 2°F 1 year's record	80°F 82°F max. 103°F	3·5″ 0·5″

Table II — Appendix

SUMMARY OF DESERT AREAS DISCUSSED

(All figures approximate only)

Deserts (in approximate order of aridity)	Position: Latitude	Position: Longitude	Size (Diameters)	Altitude (in feet)
A. Libyan Erg (North Africa)	24°N – 29°N	25°E – 28°E	100 x 300 miles	Below 1,500′
B. Takla Makan (Central Asia)	37°N – 41°N	78°E – 93°E	300 x 900 miles	Above 3,000′
C. Rub' al Khali (Southern Arabia)	18°N – 23°N	45°E – 56°E	300 x 500 miles Area 150,000 sq. miles Twitchell (23)	From 200′ — 2,000′
D. Western Sahara (North Africa)	16°N – 34°N	12°W – 15°E	100 x 200 miles for each of the great ergs, Oriental and Occidental (Gautier). Others smaller	Mostly below 1,500′ with mountains to 6,000′ and even higher peaks
E. Simpson Desert (Central Australia)	23°S – 27°S (Madigan)	135°E – 139°E	200 x 300 miles Area 56,000 sq. miles (Madigan)	From sea-level to 1,000′ (Madigan)
F. Kara Kum and Kisil Kum (Western Asia)	36°N – 45°N	55°E – 68°E	Kara Kum alone, 500 x 250 miles	1,000′ or less
G. Chihuahua*, the sand and dune area (Mexico)	31°N – 32°N	106°W – 107°W	100 x 100 miles Shreve (53)	3,000′ — 5,000′
H. Thar (North-west India)	24°N – 29°N	69°E – 75°E	400 x 240 miles	1,000′ or less

* Some doubt is still felt about the relative degree of aridity of the Chihuahua Desert

Table III — Appendix

SUMMARY OF DESERT VEGETATION

Great Libyan Erg or Sand Sea:

Parallel sand-ridges completely bare. Rare bushes of *Ephedra* to be seen. There are indications that very localized ephemeral patches of *Aristida* may spring up after rain, which falls possibly once in eight years. Entirely uninhabited.

Takla Makan:

Parallel sand-ridges completely bare. Peripheral regions of the desert have solitary *Tamarix,* holding mounds or "cones" of sand, and almost as hardy is *Populus,* the "tograk" or desert poplar. These occur as miserable shrubs or a mass of dead twigs; near the rivers they form dense groves. Rare patches of a small reed *(Lasiogrostis)* occur in the dunes. Ephemerals absent. Entirely uninhabited.

Rub' al Khali or Empty Quarter:

A varied terrain including bare parallel sand-ridges. Stretches of, say, 20 miles without vegetation, either dead or living, are rare. The most important plants are the widespread "Abal" *(Calligonum)* a large shrub, and "Hadh" *(Salsola)* a small shrub. A few other plants are frequent and there is, with little doubt, an ephemeral vegetation after the infrequent rains. Penetrated on the borders by nomad camel herders in good seasons.

Western Sahara:

A varied region including some large dune-areas or ergs. Some are humid and provide some water and grazing for flocks and herds, others are bare and difficult to penetrate; vegetation probably includes the perennial "drinn" grass *(Aristida pungens)* and shrubs of the genera *Cornulaca* (Chenopodiaceae) and *Calligonum* (Polygonaceae). After rains there may be a rich ephemeral vegetation, chiefly of cruciferous herbs. Most of the ergs allow of occasional nomad camel grazing at the edges, at least.

Simpson Desert:

The whole area covered with long, parallel dunes, quite well vegetated with shrubs and occasional small trees. Plants are thickest on the lower dunes and corridors between, where they are usually some feet apart. The crests of the dunes are, for the most part, relatively bare and unstable, though completely covered dunes occur in patches. *Triodia Basedowii,* more or less alive, is quite the most conspicuous bush of the corridors and lower slopes (Porcupine Grass or falsely called "Spinifex"). True *Spinifex paradoxus* (now *Zygochloa paradoxa*) is the sparse shrubby dominant of the ridges. There is an assortment of associated perennials, annuals and ephemerals, some attaining local dominance. Uninhabited; water is lacking.

Kara Kum:

Chiefly sand-desert with bare, parallel dunes bordering the river. They are unstabilized, but the large grass *Aristida pennata* var. may occur on the lower slopes, with some chenopodiaceous shrubs in the hollows. The barchans often become well covered with vegetation, forming shrubby sandhills and eventually dwarf forests of Saxaul trees. The vegetation is varied and largely endemic. An ephemeral flora occurs in spring. Shepherds and their flocks make sporadic excursions from the oases and river valleys, and the dwarf forests yield firewood.

Chihuahua:

The smallest of the deserts considered here, including some parallel dune areas almost bare of vegetation; what occurs is shrubby, sparse and irregular. Ephemeral vegetation probably present from time to time. Degree of habitation not known. The vegetation seems to be modified Mesquite *(Prosopis)* formation, dominated by *Poliomintha* (Labiatae).

Thar:

Large parallel sand-ridge areas are present, probably even better vegetated than the Kara Kum, with a variety of shrubs and some small trees. Sparsely inhabited, with scattered villages and numerous flocks and herds of camels, goats, cattle and sheep. There are comprehensive land survey maps of the region available. Important genera are *Calotropis, Crotalaria, Calligonum, Cyperus,* etc.

Table IV — Appendix

Summary of Chief Families and Genera represented

A. Libyan Erg

Ephedra (Gnetaceae)

Traces of Gramineae

B. Takla Makan

Tamarix (Tamaricaceae)

Populus (Salicaceae)
Lasiogrostis (Graminea)

C. Rub' al Khali

Salsola (Chenopodiaceae)
Cornulaca (Chenopodiaceae)
Calligonum (Polygonaceae)

Dipterygium (Cruciferae)
Cyperus (Cyperaceae)
Fagonia (Zygophyllaceae)
Tribulus (Zygophyllaceae)

D. Western Sahara

Aristida (Gramineae)
Cornulaca (Chenopodiaceae)
Calligonum (Polygonaceae)
Savignya (Cruciferae)

Moricandia (Cruciferae)
Malcolmia (Cruciferae)
Launea (Compositae)
Plantago (Plantaginaceae)
Ephedra (Gnetaceae)

E. Simpson Desert

Triodia (Gramineae)
Zygochloa (Spinifex) (Gramineae)
Acacia (Leguminosae)
Cassia (Leguminosae)
Crotalaria (Leguminosae)
Hakea (Proteaceae)
Grevillea (Proteaceae)
Eremophila (Myoporaceae)

Sida (Malvaceae)
Hibiscus (Malvaceae)
Portulaca (Portulacaceae)
Salsola
Rhagodia
Kochia
Bassia
Atriplex
Enchylaena
(Chenopodiaceae) All present to some extent

F. Kara Kum

Aristida (Gramineae)
Agriophyllum (Chenopodiaceae)
Arthrophytum (Saxaul) (Chenopodiaceae)
Corispermum (Chenopodiaceae)
Horaninowia (Chenopodiaceae)
Salsola (Chenopodiaceae)

Calligonum (Polygonaceae)
Smirnovia (Leguminosae)
Ammodendron (Leguminosae)
Acacia (Leguminosae)
Eremosparton (Leguminosae)
Astragalus (Leguminosae)
Carex (Cyperaceae)

G. Chihuahua Desert

Poliomintha (Labiatae)
Yucca (Liliaceae)
Prosopis (Mesquite) (Leguminosae)
Dalea (Leguminosae)

Hymenoclea (Compositae)
Senecio (Compositae)
Chrysothamnus (Compositae)
Sporobolus (Gramineae)
Andropogon (Gramineae)

H. Thar Desert

Calotropis (Asclepiadaceae)
Leptadenia (Asclepiadaceae)
Indigofera (Leguminosae)
Crotalaria (Leguminosae)
Aerua (Amarantaceae)

Calligonum (Polygonaceae)
Cyperus (Cyperaceae)
Panicum (Gramineae)
and others (Gramineae)

SOUTHERN AUSTRALIAN GASTROPODA PART III

BY BERNARD C. COTTON

Summary

Shell pyriform, with flattened base; base spreading, with a sharp edge round the entire circumference; dorsal part of the margin, on the right side, anteriorly and posteriorly obscurely ribbed; the left margin edge medially wavy; dorsum sharply humped, the central portion of the dorsum in the holotype mostly white through the outer layer of shell being dissolved away with hydrochloric acid; normally the dorsum is light brown as shown by patches of the original outer layer left in other specimens which have also been treated with acid; margins and extremities calloused and spread; medium brown-coloured base becoming cream towards the lips at the aperture; aperture wide and curved; outer anterior lip declivous; aperture turns sharply left towards the posterior end; twenty-seven teeth covering the whole length of the aperture; teeth moderately developed, produced slightly across the base, rather coarse and widely spaced, brown with cream interspaces; fossula white, slightly concave, sulcus wide and shallow, neither denticulate; interior of shell, examined in a broken specimen, ivory white. Length 49 mm., width 35 mm., height 25 mm., animal unknown.

SOUTHERN AUSTRALIAN GASTROPODA
PART III

By BERNARD C. COTTON *

[Read 8 April 1948]

Two new species and one new genus of Gastropods from south-western Australia are described here

Zoila rosselli, sp. nov.

Pl. I, fig. 1-6

Shell pyriform, with flattened base; base spreading, with a sharp edge round the entire circumference; dorsal part of the margin, on the right side, anteriorly and posteriorly obscurely ribbed; the left margin edge medially wavy; dorsum sharply humped, the central portion of the dorsum in the holotype mostly white through the outer layer of shell being dissolved away with hydrochloric acid; normally the dorsum is light brown as shown by patches of the original outer layer left in other specimens which have also been treated with acid; margins and extremities calloused and spread; medium brown-coloured base becoming cream towards the lips at the aperture; aperture wide and curved; outer anterior lip declivous; aperture turns sharply left towards the posterior end; twenty-seven teeth covering the whole length of the aperture; teeth moderately developed, produced slightly across the base, rather coarse and widely spaced, brown with cream interspaces; fossula white, slightly concave, sulcus wide and shallow, neither denticulate; interior of shell, examined in a broken specimen, ivory white. Length 49 mm., width 35 mm., height 25 mm., animal unknown.

Loc.—Fremantle, W. Aust.

Remarks—The species is constant in character, size and shape. Only three distinct species and four subspecies of the primitive cold water cowries belonging to the genus *Zoila* are known, and they are found in Western and South Australia. There are four Tertiary species in the Miocene of Victoria, *Z. consobrina* McCoy 1877, *Z. platypyga* McCoy 1876, *Z. simplicior* Schilder 1935 and *Z. toxorhyncha* Tate 1890. None of the Tertiary species resembles the Recent one here described. Probably *Z. rosselli* is more closely allied to *Zoila decipiens* Smith 1880 described from North-Western Australia than to any other species, but it is distinct. *Z. rosselli* differs in the flattened base with its spreading and sharply-edged margin and coarse spaced teeth of the columella and outer lip. Curiously, *Z. rosselli* has the general shape of *Siphocypraea mus* Linne 1758 Mediterranean, and of *Bernaya teulerei* Cazenavette 1846 Arabia, and *Bernaya fultoni* Sowerby 1903 Natal, but these three species have well-rounded bases, and *Bernaya* is edentulous. *Syphocypraea* has a complete set of spaced teeth on the margins of the wide aperture, a feature which in some way recalls *Z. rosselli*. The holotype specimen D. 14220 is figured in five different positions, and another broken specimen belonging to the series is figured to show the interior structure.

Mr. Harold Rossell, after whom the new species is named, took the four specimens before me at Fremantle from a beach near North Wharf just beyond the wall where all sorts of rubbish come ashore. The bucket dredges dump their contents straight out to sea opposite this little beach, and the shells may have come from the bottom of the harbour. He writes: "I remember small stones, some with shells such as *Turbo setosus* stuck in them in a partly fossilised state. . . . I often picked up immature *Cypraea scotti* on this little beach, but of course *scotti* were

* South Australian Museum, Adelaide.

and some actually had the remains of their animals in. . . . If I remember, the time would be about October, after the equinoctial blows of September." Mr. Rossell also remarks that "it must be a long time since I took them. . . . at least thirty years ago. I remember it very well, and the dorsum was pale brown, somewhat marked with tiny scratches and cleaned at once with the application of hydrochloric acid. I imagined then that it effected an improvement in the shell's appearance, but I was just beginning to collect things, and had it been recently I would have known better." The only specimens known are six taken by Mr. Rossell, four of them in the W. R. Steadman Collection, one of which, the holotype, described, was donated by Mr. Steadman to the South Australian Museum. One specimen from Cottesloe is in the Australian Museum, according to information received.

Alcyna acia sp. nov.

Pl. I, fig. 7, 8

Shell small, conical, turbiniform, solid, protoconch finely spirally furrowed and blunt, of one and a half whorls; first spire whorl convex, closely lirate with seven close-set cords; third convex, bicarinate, upper carina at about the centre of the whorl, lower immediately above the suture; about ten stout roundish axials from the suture cross and form somewhat vertically compressed nodules on the upper carinae and on the intercarinal lirae, least prominent on the medial lirae, more prominent on the lower carina and largest on the upper; round the base are ten rather broad, rounded spirals; mouth nearly circular, labrum bevelled on the inside, slightly effuse at the base, hollowed on its surface, without any spreading callus; columella with a prominent tooth which is actually a plait; a broad band of rosy tint winds round the base to the basal lip and extends between the tubercles of the lower carina and so can be seen as spots just above the suture; in some specimens a narrow red band appears between the main axials just below the suture and in some a series of dashes extends from its inner margin to the base nearly to the aperture of the shell; the lip is round, smooth inside, with a slight gutter behind; the body whorl has seven or eight equidistant round ribs of sizes equal to the interspaces; some have axial red lines equal in width to the white interspaces, sometimes broken into articulated lines, especially about the periphery of the body whorl, much less over the base; the first and second whorls may be red and the body whorl with seven or eight streaks of red with equally wide streaks of white from the suture to the periphery, and coral red base; some have the first three whorls red, the next two whorls, the ultimate and penultimate, with about six zig-zag broad brown flames and rather narrower white interspaces extending to a brown base; one form has the two carinations articulated with brown, the rest of the shell being light chestnut brown, the first and second whorls being rosy red. Diameter 1·8 mm.; height 3 mm.

Loc.—W. Aust.: Rottnest (type), King George Sound, Hopetoun. S. Aust.: Cape Borda, 60 fathoms.

Remarks—The species is bicarinate and more strongly sculptured than *Alcyna australis* Hedley 1907, from Mast Head Island, 17-20 fathoms; the columellar tooth is less developed, and the colour pattern is different.
Holotype: Reg. No. D. 14219, South Australian Museum.

Austroliotia gen. nov.

Genotype: *Liotia botanica* Hedley 1915, New South Wales.

Shell depressed, moderately heavily sculptured, aperture trumpet-shaped, not

strongly variced; umbilicus wide; operculum horny, multispiral but with faint traces of granules.

Distribution—New South Wales, Victoria, South Australia, Western Australia, Tasmania, New Zealand.

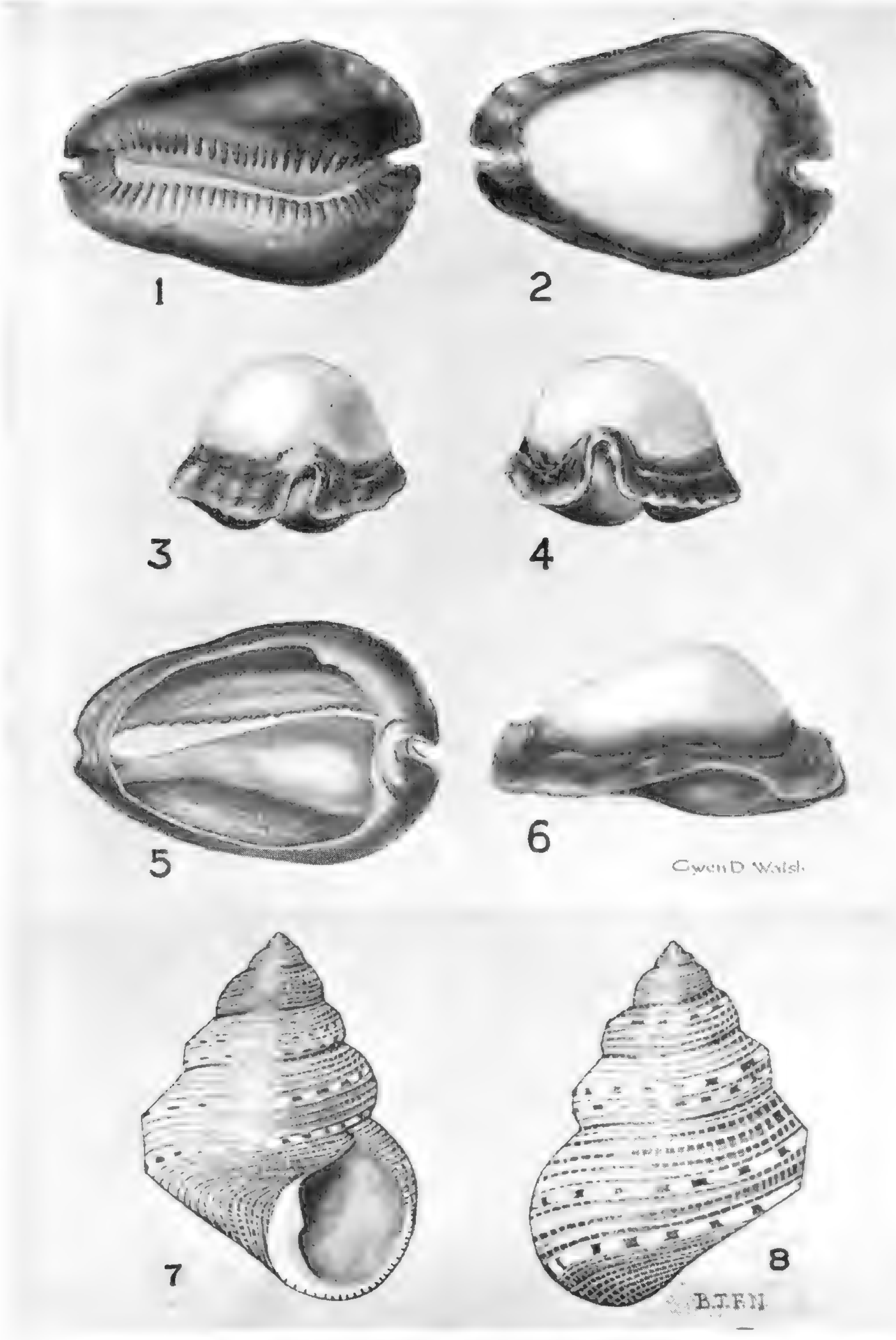
Remarks—*Liotina* Fischer 1885, genotype *L. gervillei* Defrance, a fossil, has been used for this temperate Australasian genus with widely umbilicate depressed shells, with moderately variced aperture and simple, multispiral, horny, operculum. *Liotina* is more applicable to a well marked tropical and subtropical group of species, with extremely solid, not very depressed shells having a very narrow cylindrical perforation. The genotype, *A. botanica,* typical of a southern Australian series, seems to be a temperate relative of the warm water *Liotina. Austroliotia* is separable from *Munditia,* in which the shell is more planorbid with a tendency to reduction of sculpture to knobs on the double keel, and having a very wide perspective umbilicus, lightly variced aperture and simple, horny, multispiral operculum. Species belonging to *Austroliotia,* besides the genotype, are *A. australis* Kiener, *A. densilineata* Tate, and others may also belong here.

KEY TO SPECIES OF AUSTROLIOTIA

a. Spiral lirae defined .... *australis*
aa. Spiral lirae weak .... *densilineata*

DESCRIPTION OF PLATE 1

Fig. 1 **Zoila rosselli** sp. nov., ventral, holotype.
Fig. 2 **Zoila rosselli** sp. nov., dorsal, holotype.
Fig. 3 **Zoila rosselli** sp. nov., anterior, holotype.
Fig. 4 **Zoila rosselli** sp. nov., posterior, holotype.
Fig. 5 **Zoila rosselli** sp. nov., dorsal aspect of broken specimen showing interior.
Fig. 6 **Zoila rosselli** sp. nov., lateral, holotype.
Fig. 7 **Alcyna acia** sp. nov., ventral.
Fig. 8 **Alcyna acia** sp. nov., dorsal.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A VEGETATION AND PASTURE SURVEY OF COUNTIES EYRE, BURRA AND KIMBERLEY, SOUTH AUSTRALIA

By R. W. Jessup

Summary

In the past, ecological studies of the natural vegetation in South Australia have had as their objective the classification, mapping and description of the floristics of the plant communities, together with an enumeration of the edaphic and climatic factors responsible for their maintenance. The present work has a similar approach. Throughout most of the region discussed the natural plant assemblages are used as the basis of a sheep-grazing industry. Some consideration is given, therefore, to the plant associations as natural pastures. Their species composition and the frequency of occurrence of the fodder plants are included in the lists giving the floristics of the association. The ultimate aim of this work, however, is to present an accurate picture of the distribution of the species which occur in the area and their total rainfall requirements. Over much of the country the soils are comparatively uniform, enabling the sifting effect of declining rainfall on the species composition of the plant assemblage to be studied. It was fortunate that the field work was carried out in three very favourable years – 1945, 1946 and 1947.

A VEGETATION AND PASTURE SURVEY OF COUNTIES EYRE, BURRA AND KIMBERLEY, SOUTH AUSTRALIA

By R. W. Jessup *

[Read 10 June 1948]

INTRODUCTION

In the past, ecological studies of the natural vegetation in South Australia have had as their objective the classification, mapping and description of the floristics of the plant communities, together with an enumeration of the edaphic and climatic factors responsible for their maintenance. The present work has a similar approach. Throughout most of the region discussed the natural plant assemblages are used as the basis of a sheep-grazing industry. Some consideration is given, therefore, to the plant associations as natural pastures. Their species composition and the frequency of occurrence of the fodder plants are included in the lists giving the floristics of the association. The ultimate aim of this work, however, is to present an accurate picture of the distribution of the species which occur in the area and their total rainfall requirements. Over much of the country the soils are comparatively uniform, enabling the sifting effect of declining rainfall on the species composition of the plant assemblage to be studied. It was fortunate that the field work was carried out in three very favourable years—1945, 1946 and 1947.

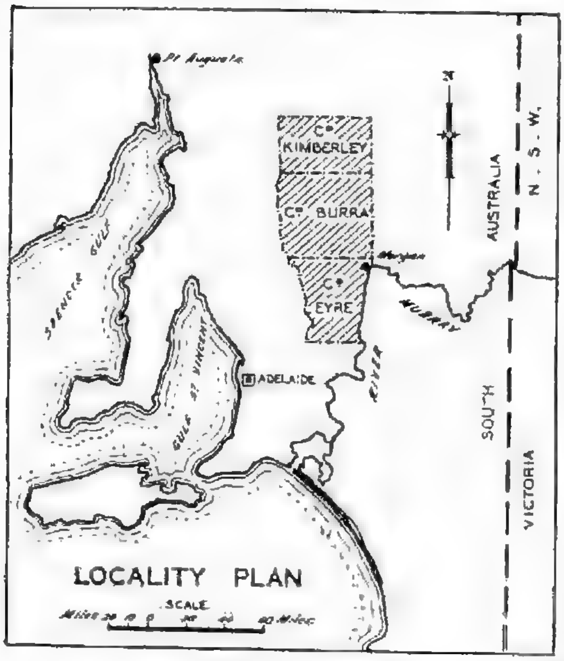

Fig. 1

The area considered in this paper comprises Counties Eyre, Burra and Kimberley, a total of about 6,000 square miles of country. Reference to the locality plan (fig. 1) shows that the three Counties extend from the eastern scarp of the Mount Lofty Ranges to the longitude of the River Murray, bounded in the south by a line from Swan Reach to Cambrai, while the northern boundary lies slightly south of the Broken Hill railway line. Since by far the greater portion is semi-arid or arid—and even where the rainfall is higher skeletal soils are widespread—little cropping is carried out, the land being mainly used for sheep-grazing (fig. 2). Further, the low and unreliable rainfall limits the possibilities of plant introduction and pasture improvement, so that grazing is dependent on the drought-resistant native species. Overgrazing of these pastures has caused widespread degeneration of the plant cover, with resultant loss in stability of the soils. Wheat was formerly much more widely grown, especially in Counties Eyre and Burra, but unfavourable results caused recession of the wheat-growing areas and their reversion to grazing.

* Assistant Soil Conservator, Department of Agriculture, Adelaide.

CLIMATE

While the southern portion of the area has a typical Mediterranean climate with rainy winters and dry summers, this tendency towards a maximum of rain in the winter is not so pronounced in the north where summer rains are an important feature. This is shown in Table I, which sets out the monthly rainfalls of four recording stations:

TABLE I

Mean monthly and annual rainfalls of four recording stations.

	Sedan	Burra	Paratoo	Oodlawirra
January - -	66	79	61	96
February - -	58	72	60	71
March - -	65	83	64	60
April - - -	89	122	46	74
May - - -	123	192	88	103
June - - -	149	231	90	120
July - - -	117	213	52	103
August - -	150	226	72	134
September -	132	205	72	104
October - -	109	166	66	81
November - -	72	94	80	91
December - -	65	94	78	96
Total - -	1,195	1,777	829	1,133

The summer rains are associated with thunderstorms which are of monsoonal origin. A characteristic of many of the rains associated with summer thunderstorms in the northern pastoral areas is the scattered nature and sharply-defined limits of the showers. Occasionally, extremely severe hail and wind accompanies the thunderstorm and much damage is done to the vegetation. These storms usually only cover a narrow strip of country. In Table II a comparison is made of the monthly rainfalls of the Gums and Florieton, two recording stations separated by four miles of plain, for three years during which there were significant differences in the annual rainfalls. It is noteworthy that the biggest differences in monthly rainfall occur during the months when thunderstorms are most often experienced. In several instances no rain was recorded during the month for one station, while the other had useful rain.

TABLE II

Rainfall characteristics of The Gums and Florieton for 1892, 1899 and 1926

		Monthly Rainfall												Annual Rainfall		
Year		J.	F.	M.	A.	M.	J.	Jy.	A.	S.	O.	N.	D.	Gums	Florieton	Diff.
1892 -	Flor.	118	71	—	40	32	45	89	123	157	429	92	59	1,002	1,255	253
	Gums	90	40	—	28	31	31	68	113	121	386	48	46			
1899 -	Gums	10	232	50	33	33	201	26	50	172	30	46	15	899	748	151
	Flor.	—	165	55	27	20	173	—	60	238	—	—	10			
1926 -	Flor.	—	—	14	47	191	97	33	266	161	142	—	31	875	982	107
	Gums	—	—	11	34	209	65	45	145	292	38	23	13			

The summer rains are of higher intensity than the winter rains (Table III).

TABLE III

Showing the difference in intensity of the summer and winter rains.

THE GUMS 1919-1942

	J.	F.	M.	A.	M.	J.	Jy.	A.	S.	O.	N.	D.	Year
Average number of wet days - - - -	2.3	2.0	1.8	2.3	4.3	5.4	5.8	5.9	4.3	3.3	2.6	2.3	85.0
Rainfall (points) per wet day - - -	32	36	26	21	21	13	12	17	18	22	24	24	

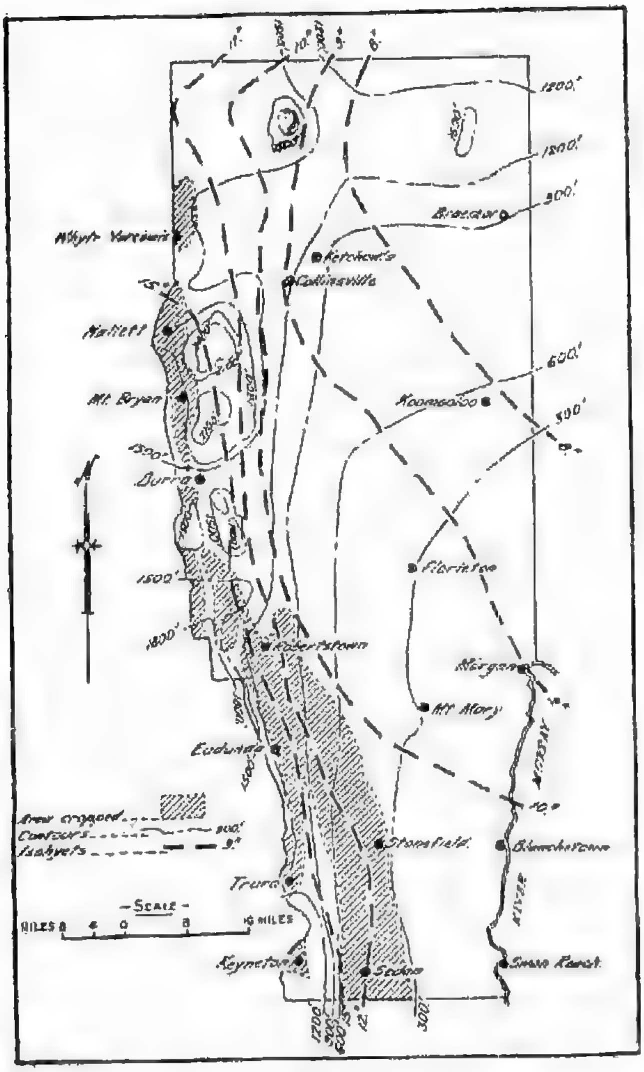

Fig. 2.

Rainfall isohyets are shown in fig. 2. The average annual rainfall varies from 23″ in the extreme south-west to 7″ in the north-east of the area. Physiographic features influencing rainfall are the north-south ranges along the western boundary which are part of the Mount Lofty - Flinders Ranges system, and the level plains which are characteristic of the country east of the ranges. Along the ranges the isohyets follow elevation in a general way, while on the plains rainfall decreases from south to north.

No temperature records are available from any locality within the area. Summers are warm to hot and winters cold to mild. June and July are the coldest months, and in these two months in particular, especially in the north, fairly heavy frosts are common. Falls of snow occur very rarely in the highlands around Hallett and Burra, which are in one of the coldest portions of the State.

During the summer months, particularly in drought years, dust-storms are frequently experienced. They result in a mantle of dust forming on the shrubs, particularly the saltbush and bluebush, due to their hairy leaves and stems.

The distribution of the vegetation in the area considered in this paper is determined primarily by climate, soils being of lesser importance. Of the climatic factors the rainfall-evaporation ratio which gives a measure of the moisture available to the plants is most important, since temperature is rarely a limiting factor to plant growth except in the Burra and Hallett highlands. Davidson (4) considers that for general plant growth, if during any period P/E exceeds 0·5, sufficient moisture is available. Most of Counties Kimberley, Burra and Eyre are within Davidson's warm-temperate semi-arid zone with P/E exceeding 0·5 for five months of the year during the May-October period and nil months for the November-April period. In a portion of the north-east P/E exceeds 0·5 for only four months (May-October period). However, along the ranges of the western boundary P/E exceeds 0·5 for seven months of the year (six during the May-October period and one during the November-April period). Mean annual temperatures are between 60-65° F.

Considering herbage plants specifically and from direct observations at the Waite Institute, Trumble (12) considers it necessary for P/E to exceed 0·3 if the surface four inches of soil is to be maintained above the wilting point. Rain falling during the period in which P/E exceeds 0·3 he terms the influential rainfall. For most of the area studied P/E exceeds 0·3 for less than five months of the year, although it is six in the south-western portion along the ranges. The influential rainfall decreases from about 15″ per year to less than 5″.

GEOLOGY AND PHYSIOGRAPHY

The mallee plains are composed of level-bedded Tertiary limestones, while the outcropping rocks of the ranges are of Precambrian and Cambrian age. Hossfeld (6) has described the geology of the eastern scarp of the Mount Lofty Ranges between Keyneton and Dutton. A feature of the north-western portion of the area is the system of alternating ridges and valleys, which have a pronounced north-south trend. This area is continuous with County Victoria, where a similar topography has been described by Stephens (11).

Drainage is largely endoreic, although the River Marne and the Burra Creek following heavy rains flow into the River Murray. The eastern scarp of the ranges is steep and the sharp gradient, especially during summer thunderstorms, causes the creeks to carry much alluvial material onto the foothill plains. Here the creeks flood out in alluvial basins. The drainage pattern of the plains of the north-east is characterised by watercourses, which unlike creeks are not defined by banks, but are broad depressions lacking a well-defined channel. They are particularly valuable to the grazier for their production of herbage following rains which may have caused little response on the higher ground. Overgrazing of the watercourses and consequent destruction of their protective bush cover results in scouring and the formation of channels. The water no longer spreads over the broad extent of the watercourse but is confined as in a creek. At this stage the watercourse has lost most of its grazing value.

The surveyed area varies from about 300-3,000 feet above sea level (fig. 2), the highest land being in the vicinity of Burra and Hallett. Mount Bryan (3,063 feet) is the highest peak.

THE SOILS

Four major soil groups are represented in the area, and also allied skeletal soils. Their distribution is shown on the soil plan. They are:

1. podsols and podsolic soils;
2. red-brown earths;
3. brown solonized soils;
4. desert loams; and
5. skeletal soils allied to the above groups

Podsols and podsolic soils

The podsols are restricted to a small area in the extreme south-west, where the rainfall exceeds 22″ per annum. The underlying rock is generally within about 2 feet of the surface and outcrops on the ridges, although there are deeper alluvial soils in the valleys. Soil profiles show a grey sandy loam overlying yellow-grey sandy loam, and a subsoil consisting of mottled yellow and yellow-brown or grey and yellow-brown sandy clay loam or clay.

Fringing the true podsols on the lower rainfall side is a zone of grey-brown podsolic soils whose subsoils are yellow-brown and unmottled.

Red-brown earths

The red-brown earths have been considered in detail by Piper (8) and are not further discussed here. Included in the red-brown earths shown on the soil map is a small area of degraded rendzina of the Yangya silty loam type, as described by Stephens (11).

Table IV sets out the results of laboratory analysis of a red-brown earth profile collected one mile south of Whyte-Yarcowie (8).

TABLE IV

Laboratory analysis of a red-brown earth profile.

Locality of sample: Section 515, Hd. Whyte

Depth	0–5″	5–14″	14–19″	19–25″
Horizon	A	B_1	B_2	B_2C
Reaction	7·1	7·4	7·6	8·2
	%	%	%	%
Coarse sand	17·6	14·7	6·1	5·4
Fine sand	35·9	26·8	12·8	13·5
Silt	16·8	9·3	5·7	6·3
Clay	24·2	41·8	64·4	58·1
Loss on Acid Treatment	1·1	1·5	2·0	11·0
Nitrogen N	·102	·067	·077	·074
Phosphoric Acid P_2O_5	·055	·050	—	—
Potash K_2O	0·83	1·06	—	—
Chlorides as NaCl	0·011	0·015	0·020	0·020

Brown solonized soils

These are the most widespread soils in the area, since they occupy the mallee plains. The brown solonized soils have been described by Prescott (9) and in detail by Prescott and Piper (10), and later by Crocker (3).

They are usually sandy loams averaging a depth of about 6″ and overlying a layer containing abundant nodular limestone and some hardpan, but the latter is not so strongly developed as further south (7). Beneath this layer of maximum lime accumulation is a zone containing much friable lime and clay. Tertiary limestones are found at shallow depths. Along the foot of the ranges where rainfall is higher, the soils contain less lime and have a deeper A horizon and a well-developed sandy clay loam subsoil. The brown solonized soils tend to grade into red-brown earths, but the line of demarcation is usually made definite by the interpolation of skeletal soils. Along the River Murray the surface soil is extremely shallow (1-2″) and travertine limestone is exposed over wide areas.

Results of laboratory analysis of a brown solonized soil profile collected near Morgan are given in Table V (10).

TABLE V

Laboratory analysis of a brown solonized soil profile.

Locality of sample: Section N, Hd. Cadell

Depth	0–4″	4–9″	9–36″	36–66″	66–85″
Horizon	A	A	B	BC	C
Reaction	8·7	8·7	lime-	8·8	8·8
	%	%	stone	%	%
$CaCO_3$	5·0	6·6		10·5	25·4
Coarse sand	36·2	32·3		6·1	5·0
Fine sand	41·3	43·9		23·9	20·9
Silt	4·7	4·7		6·3	4·3
Clay	7·9	7·7		43·6	30·4
Nitrogen N	·080	·081		·020	·014
Phosphoric Acid P_2O_5	·049	·050		·039	—
Potash K_2O	·52	·50		1·65	—
Chlorides as NaCl	·007	·021		·406	·419

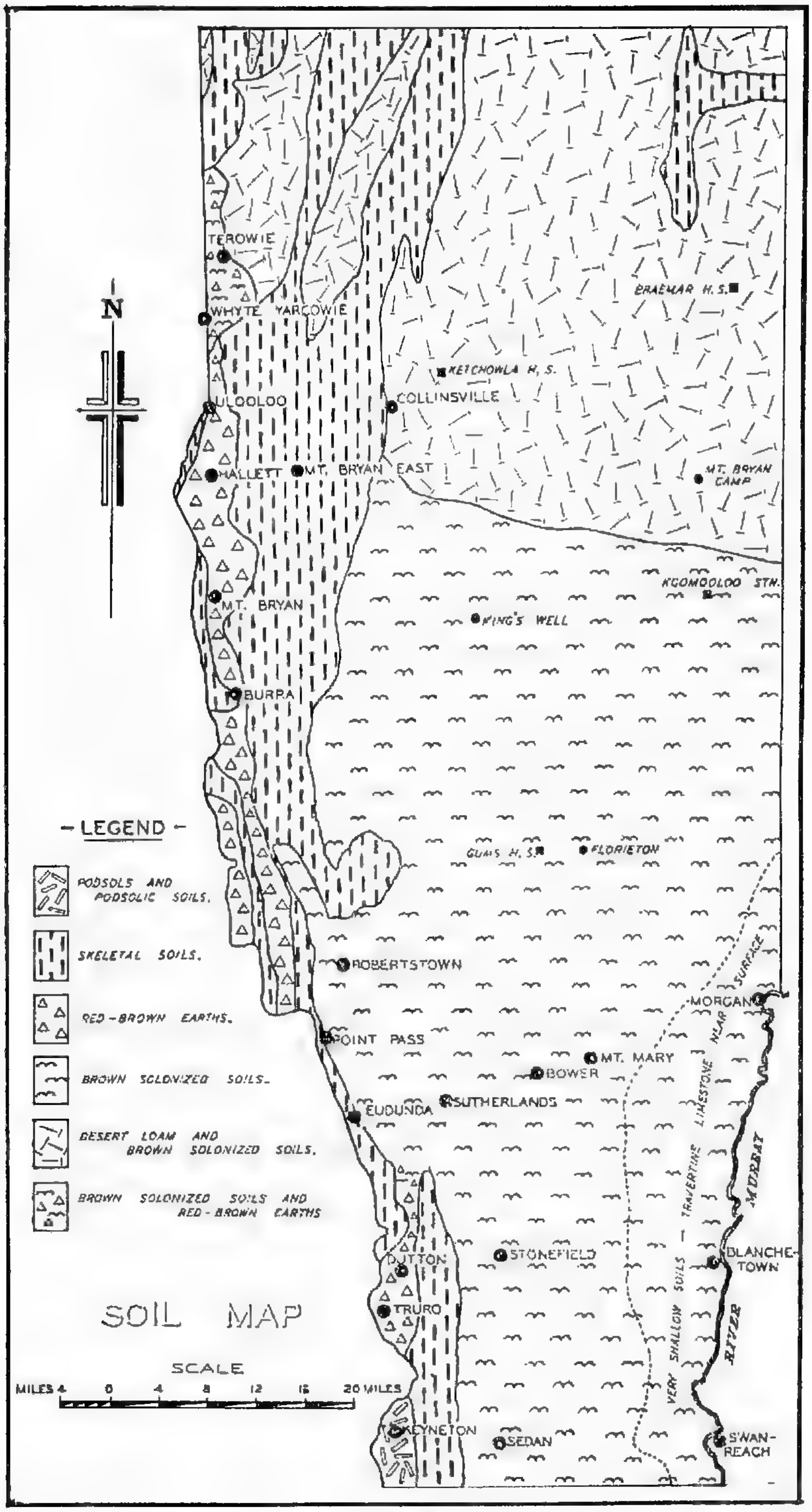
TEROWIE
WHYTE YARCOWIE
ULOOLOO
HALLETT
MT. BRYAN EAST
COLLINSVILLE
KETCHOWLA H. S.
BRAEMAR H. S.
MT. BRYAN CAMP
KOOMOOLOO STN.
KING'S WELL
MT. BRYAN
BURRA
GUMS H. S.
FLORIETON
ROBERTSTOWN
MORGAN
POINT PASS
MT. MARY
BOWER
SUTHERLANDS
EUDUNDA
STONEFIELD
BLANCHE-TOWN
DUTTON
TRURO
KEYNETON
SEDAN
SWAN-REACH
MURRAY
RIVER
VERY SHALLOW SOILS — TRAVERTINE LIMESTONE NEAR SURFACE
N
- LEGEND -
PODSOLS AND PODSOLIC SOILS.
SKELETAL SOILS.
RED-BROWN EARTHS.
BROWN SOLONIZED SOILS.
DESERT LOAM AND BROWN SOLONIZED SOILS.
BROWN SOLONIZED SOILS AND RED-BROWN EARTHS
SOIL MAP
SCALE
MILES 4 0 4 8 12 16 20 MILES

Fig. 3

THE DESERT LOAMS

Two types of desert loam soils are found in the area surveyed:

(1) Calcareous desert loams in which moderate lime occurs.

(2) Desert loams in which small amounts of lime may be present.

The following is a typical calcareous desert loam profile:

0- 7″	dull brown sandy loam;
7-15″	dull brown loam with moderate lime;
15-30″	brown clay loam;
30-58″	red-brown clay;
58″-	red-brown clay with slight gypsum.

The depth at which lime is encountered varies from 6-20″. Gypsum is not always detected in the subsoils.

In the less calcareous desert loams the surface soil is a brown loam, that is, these soils are characteristically heavier textured and have a somewhat brighter colour in the surface horizon. Nodular lime is absent from the profiles, but light lime may be found at a depth of about 3 feet. These desert loams, therefore, have less lime, and any lime which is present is at greater depth than in the calcareous desert loams.

The two types of desert loam profiles, moreover, are found in different sites, those containing little lime being characteristic of watercourses while the calcareous soils are present in higher sites.

Calcareous desert loams carry *Kochia sedifolia* as the shrub dominant, while *K. planifolia* and *Atriplex vesicarium* are associated with the less calcareous soils.

Results of laboratory analysis of a desert loam profile are shown in Table VI.

TABLE VI

Results of laboratory analysis of a desert loam.

Data supplied by Mr. C. G. Stephens, Waite Institute.

Locality of sample: Block 36, Hd. of Walloway

Depth	0–1″	1–5″	5–7″	7–10″	10–22″	22–36″	36–
Coarse sand	21·8	7·9	7·1	6·6	3·9	2·6	2·2
Fine sand	49·5	50·0	34·4	33·2	20·7	30·5	29·6
Silt	10·5	17·8	33·0	31·8	19·5	28·6	32·4
Clay	15·9	19·6	22·3	24·8	49·5	28·1	29·7
Loss on Acid Treatment	1·3	1·3	1·2	2·2	1·4	7·2	4·6
Reaction	8·67	8·69	8·17	8·23	8·28	8·82	8·73
Total Sol. Salts	·064	·085	·128	·085	—	·166	·302
$CaCO_3$	—	·070	—	—	·042	5·22	—
Potash K_2O	—	1·284	—	—	—	—	—
Phosphoric Acid P_2O_5	—	·075	—	—	—	—	—
Nitrogen N	—	·127	·104	·076	—	—	—

Skeletal soils

Shallow immature non-arable soils are associated with the ranges. Country rock frequently outcrops, or the soils are very shallow and contain an abundance of rock fragments.

THE VEGETATION

Eleven plant associations have been recognised and mapped. Table VII sets out the factors determining their distribution. Climate, particularly rainfall, is

most important, while soils play a very minor role in determining the distribution of the associations but determine the distribution of some species within the associations.

TABLE VII
Plant Associations

E. camaldulensis	Savannah woodland	podsols	>23″
E. leucoxylon	Savannah woodland	red-brown earth, podsols, skeletal	19–23″
C. stricta	Savannah woodland	skeletal, brown solonized	14—19″
E. odorata	Savannah woodland	skeletal, brown solonized	14—19″
L. multiflora-L. dura	Savannah	skeletal, red-brown earth, brown solonized, desert loam	10½–18″
E. anceps-E. dumosa	mallee scrub	brown solonized	12–14½″
E. brachycalyx-E. oleosa	mallee scrub	brown solonized, skeletal	10½–12″
E. oleosa-E. gracilis	mallee scrub	brown solonized, skeletal	8–10½″
M. platycarpum-K. sedifolia	tree-shrub steppe	brown solonized, desert loam	<8″
C. lepidophloia	desert scrub	brown solonized, desert loam	<8″
Eremophila-Dodonaea-Acacia	shrubland	skeletal	9½–13½″

(1) EUCALYPTUS CAMALDULENSIS association (pl. II, fig. 1).

Red gum (*E. camaldulensis*) forms an open savannah woodland where the rainfall exceeds 23″ per annum. The habitat is undulating to hilly, while the soils are podsols. Besides being the dominant of this community, *E. camaldulensis* occurs along creeks throughout the area.

Shrubs and undershrubs are practically absent from the community. The following occur rarely: *Acacia pycnantha, A. rhetinodes, Astroloma humifusum Pimelia glauca, Daviesia ulicina, Dillwynia floribunda, Thomasia petalocalyx* and *Eutaxia microphylla. Pteridium aquilinum* is not found east of Keyne Hill.

The association is characterised by its herbaceous species, of which grasses are the most common. *Danthonia setacea, Stipa variabilis* and in parts *Trifolium subterraneum* dominate the pasture. Usually associated are *Avena fatua, Bromus rigidus, Cryptostemma calendulaceum* and *Erodium botrys.* Towards the drier limits of the *E. camaldulensis* association *Danthonia setacea* is replaced by *D. semiannularis*, a species demanding less rainfall. Commonly occurring herbaceous species are *Briza maxima, B. minor, Bromus mollis, Cynosurus echinatus, Hypochaeris radicata, Hordeum leporinum* (formerly *H. murinum*), *Trifolium angustifolium, Scirpus* sp. and *Vulpia myuros.* Less common are *Aira caryophyllea, Acaena ovina, Trifolium arvense, Rumex acetosella, Vittadinia triloba, Stipa eremophila, Halorrhagis elata* and *Themeda australis.*

Rare herbaceous species are *Convolvulus erubescens, Erodium cicutarium, Poa australis, Oxalis corniculata, Rumex pulcher, Drosera whittakeri, D. pygmaea, Scleropoa rigida, Cheilanthes tenuifolia, Enneapogon nigricans, Erechthites quadridentata, Trifolium glomeratum, Wahlenbergia* sp., *Chenopodium carinatum,*

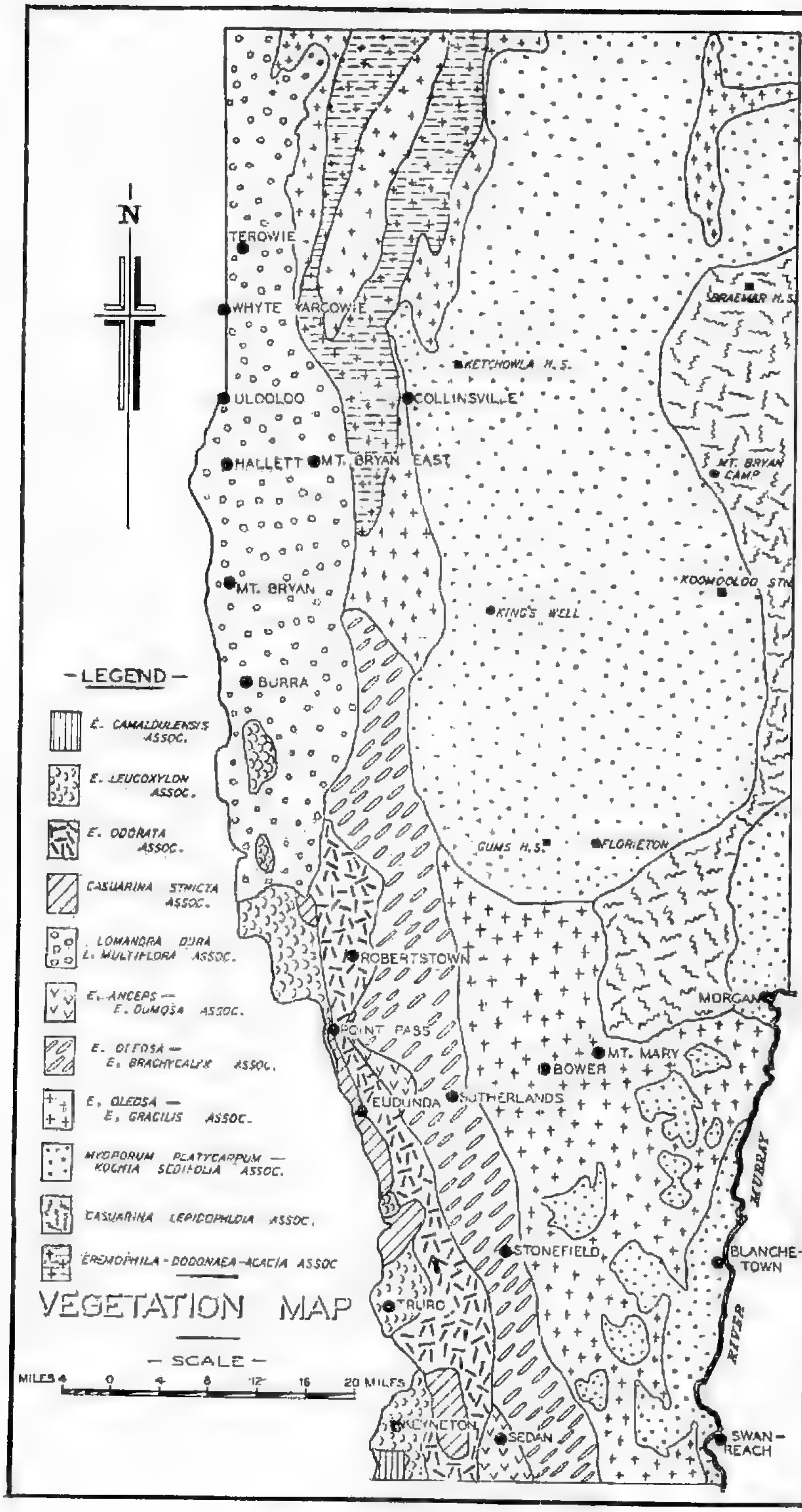
N
TEROWIE
WHYTE YARCOWIE
ULOOLOO
COLLINSVILLE
KETCHOWLA H.S.
BRAEMAR H.S.
HALLETT
MT. BRYAN EAST
MT. BRYAN CAMP
MT. BRYAN
KOONOOLOO STN
KING'S WELL
BURRA
GUMS H.S.
FLORIETON
ROBERTSTOWN
MORGAN
POINT PASS
MT. MARY
BOWER
EUDUNDA
SUTHERLANDS
MURRAY
STONEFIELD
BLANCHE-TOWN
TRURO
RIVER
KEYNETON
SEDAN
SWAN-REACH
- LEGEND -
E. CAMALDULENSIS ASSOC.
E. LEUCOXYLON ASSOC.
E. ODORATA ASSOC.
CASUARINA STRICTA ASSOC.
LOMANDRA DURA L. MULTIFLORA ASSOC.
E. ANCEPS — E. DUMOSA ASSOC.
E. OLEOSA — E. BRACHYCALYX ASSOC.
E. OLEOSA — E. GRACILIS ASSOC.
MYOPORUM PLATYCARPUM — KOCHIA SEDIFOLIA ASSOC.
CASUARINA LEPIDOPHLOIA ASSOC.
EREMOPHILA - DODONAEA - ACACIA ASSOC
VEGETATION MAP
- SCALE -
MILES 4 0 4 8 12 16 20 MILES

Fig. 4

Kennedya prostrata, Lomandra fibrata, Sonchus oleraceus, Lolium subulatum, Moraea xerospatha var. *monophylla, Stipa drummondii* and *Ranunculus lappaceus. Helichrysum apiculatum* and *Lomandra dura* are very rare.

Of the weeds present in the community *Echium plantagineum* is the most widespread. *Oxalis cernua* is of fairly common occurrence. The following are rare: *Salvia verbenaca, Asclepias rotundifolia, Iris germanica, Rosa canina, Solanum nigrum, Inula graveolens, Romulea rosea* and *Onopordon acanthium.*

Grazing and invasion by introduced species have considerably modified the native pastures. In lightly stocked paddocks the sward is dominated by the wallaby and spear grasses and contains much *Stipa eremophila* and few annuals. With grazing, *Themeda australis* (kangaroo grass) and *Stipa eremophila* are among the first species to be removed, and at the same time there is an increase in annuals like *Bromus rigidus, Avena fatua, Cryptostemma calendulaceum, Erodium botrys* and *Hordeum leporinum.* Many of the species which appear are of doubtful fodder value on account of their low production of edible growth and their short life. *Echinopogon ovatus* is particularly abundant along roadsides but is not found to any extent in grazed paddocks.

There is a notable absence of introduced pasture plants in this good rainfall country, and with the rare exception of paddocks in which subterranean clover has been planted, the pastures are grass dominant. Apart from the rarely occurring leguminous shrubs which are now found principally along roadsides, the only native legume found in the community is *Kennedya prostrata.* This does not occur in grazed paddocks. The medics which are common in other plant communities (*Medicago hispida, M. truncatula* and *M. minima*) do not grow on these acid soils, the principal herbaceous legumes being *Trifolium angustifolium* and *T. arvense.*

(2) Eucalyptus leucoxylon association (pl. II, fig. 2).

E. leucoxylon (blue gum) association covers a considerable area of the Mount Lofty Ranges and reaches the eastern-most limits of its distribution where the rainfall is about 19″ or slightly less per annum. The habitat is undulating to hilly, while the soils are red-brown earths, podsols and related skeletal soils. Near Keyneton the transition from red to blue gum is due to declining rainfall, not to any soil change. *E. leucoxylon* var. *pauperita* is also present.

Shrubs and undershrubs are not generally a conspicuous feature of the community. *Bursaria spinosa, Acacia pycnantha* and *Pimelia glauca* are rare, while *Acacia armata, A. rhetinodes, Cryptandra amara* var. *longiflora, Helichrysum retusum, Triodia irritans, Exocarpus cupressiformis* and *Sida corrugata* are very rare. In the area discussed in this paper *Daviesia ulicina, Dillwynia floribunda* and *Thomasia petalocalyx* are restricted to podsolic soils in the vicinity of Keyneton. *A. brachybotrya, Enchylaena tomentosa* and *Kochia brevifolia* are found in the driest parts of the habitat.

Callitris propinqua occurs on skeletal soils with red-brown earth affinities towards the drier limits of the community.

This association, like the red gum country, is characterised by its herbaceous species but contains more volunteer medics and clovers with the grasses. *Stipa variabilis* and *Danthonia semiannularis* dominate the sward. Usually associated species are *Vittadinia triloba, Avena fatua, Erodium botrys, Bromus rigidus* and *Hordeum leporinum.* Commonly occurring herbaceous species are *Trifolium angustifolium, Vulpia myuros, Stipa eremophila, Medicago trunculata* and *M. hispida.* The following are less common: *Erodium cicutarium, Oxalis corniculata, Cheilanthes tenuifolia, Aristida behriana, Cryptostemma calendulaceum, Trifolium arvense, T. tomentosum, Helichrysum apiculatum, Hypochaeris*

radicata, Medicago minima and *Helipterum jessenii*. Fairly rare are *Bromus madritensis, B. mollis, Scirpus* sp., *Lolium subulatum, Rhagodia nutans, Lomandra dura* and *L. multiflora* (both species being found on skeletal soils), *Wahlenbergia* sp., *Anguillaria dioica, Briza maxima, Aira caryophyllea, Plantago lanceolata, Erechthites quadridentata, Convolvulus erubescens, Sonchus oleraceus, Geranium pilosum* and *G. molle*.

Species of rare occurrence include: *Moraea xerospatha* var. *monophylla, Euphorbia drummondii, B. minor, Dianella revoluta, Trifolium subterraneum* (podsolic soils vicinity Keyneton), *Dichopogon strictus, Lolium cylindricus, Lepidium hyssopifolium, Chenopodium carinatum, Cynodon dactylon, Clematis microphylla, Kennedya prostrata, Sherardia arvensis, Enneapogon nigricans, Velleia paradoxa, Themeda australis, Halorrhagis elata, Drosera whittakeri, Salsola kali, Schismus barbatus* (the latter two species only in the driest of the blue gum area), *Acaena ovina, Trichinium spathulatum, Stipa elegantissima, Senecio lautus, Calocephalus citreus, Ranunculus lappaceus, Bulbine bulbosa, Lolium subulatum, Stipa drummondii, Trifolium glomeratum* and *Scleropoa rigida*.

Echium plantagineum is the most widespread weed. *Salvia verbenaca* and *Oxalis cernua* are fairly widespread, while the following are occasionally found, especially along roadsides: *Marrubium vulgare, Asphodelus fistulosus, Onopordon acaule, O. acanthium, Carthamus lanatus, Rosa canina, Solanum nigrum, Ulex europaeus, Cynara cardunculus, Foeniculum vulgare, Heliotropium europaeum, Romulea rosea* and *Polygonum aviculare*. *Inula graveolens* is conspicuous in wheat stubbles following summer rains.

Changes in the native pastures similar to those brought about in the red gum country by grazing and invasion by introduced species have occurred here. The most widespread soils associated with the community are red-brown earths, and these are considerably less acid than the red gum soils. As a result the medics *Medicago truncalata, M. hispida* and more particularly on the drier side the less valuable *M. minima* make a more balanced pasture. The family Leguminosae is represented by several species amongst the generally inedible and sclerophyllous shrubs, but the only native herbaceous legume is the rarely occurring *Kennedya prostrata*.

(3) Casuarina stricta association (pl. II, fig. 4).

C. stricta (sheoak) is a small tree which is found throughout the Mount Lofty Ranges, generally on shallow skeletal soils, on which it replaces the dominant tree of the mature soils of the area. It is, however, by no means restricted to such habitats, since it is found in various parts of the State on a variety of soils. In the area considered in this paper sheoak forms an open savannah woodland along portion of the eastern scarp of the ranges, but does not extend on to the foothill plains. The rainfall of the habitat, which is characterised by rough hills with skeletal soils, is between 14½" and 19" per annum. While most of the area is devoid of *Lomandra multiflora* and is really a grassland community with only scattered trees, in parts this species gives a characteristic facies to the community. It is particularly prominent towards the foot of the hills.

Shrubs and undershrubs are unimportant. *Acacia armata, A. brachybotrya* and *Rhagodia parabolica* are fairly rare, while the following are very rare: *Bursaria spinosa, Acacia pycnantha, Kochia brevifolia, Dodonaea attenuata, Enchylaena tomentosa, Pimelia glauca* and *Nicotiana glauca*.

Stipa variabilis and *Danthonia semiannularis* dominate the sward. Usually associated species are *Erodium botrys, Vittadinia triloba, Hordeum leporinum* and *Avena fatua*. Commonly occurring species are *Medicago hispida, M. truncalata*

and *M. minima*, *Trifolium angustifolium* and *Bromus rigidus*. *Cryptostemma calendulaceum*, *Trifolium arvense*, *Enneapogon nigricans*, *Hypochaeris radicata*, *Stipa eremophila*, *Vulpia myuros* and *Erodium cicutarium* are less common.

The following species are rare: *Salsola kali*, *Stipa elegantissima*, *Acaena ovina*, *Aira caryophyllea*, *Briza maxima*, *Oxalis corniculata*, *Anguillaria dioica*, *Convolvulus erubescens*, *Halorrhagis elata*, *Cheilanthes tenuifolia*, *Wahlenbergia* sp., *Chenopodium carinatum*, *Lolium subulatum*, *Moraea xerospatha* var. *monophylla*, *Sonchus oleraceus*, *Atriplex semibaccatum*, *Kennedya prostrata*, *Helichrysum apiculatum*, *Helipterum jessenii*, *Lomandra dura*, *Rhagodia nutans*, *Dichopogon strictus*, *Trichinium spathulatum*, *Bulbine bulbosa* and *Ranunculus lappaceus*.

Echium plantagineum is the most widespread weed. *Salvia verbenaca*, *Romulea rosea*, *Oxalis cernua* and *Onopordon acaule* are common. Rare are *Solanum nigrum*, *Carthamus lanatus*, *Foeniculum vulgare*, *Scabiosa maritima*, *Asphodelus fistulosus* and *Onopordon acanthium*.

Comparison of species and their frequency of occurrence shows that these pastures associated with sheoak are very similar to the native pastures of the blue gum country.

(4) Eucalyptus odorata association (pl. II, fig. 3).

E. odorata (peppermint gum) reaches its maximum development on the western slopes of the Mount Lofty Ranges and the adjacent plains. On the eastern side of the ranges the rainfall decreases sharply, so that climatically the only favourable habitats for *E. odorata* are the eastern slopes and a narrow strip along the foot of the hills. The habitat is characterised by brown solonized soils on the foothill plains and skeletal soils in the hills. The lower limit of rainfall is about 14½″ per annum. In addition to being the dominant of this community, *E. odorata* occurs in the valleys among the hills which carry *Acacia-Dodonaea-Eremophila* association and extends throughout the driest of the area along creeks.

East of Eudunda *Eucalyptus calcicultrix* is present in the community. *Callitris propinqua*, *Pittosporum phillyreoides* and *Myoporum platycarpum* are very rare, being found only on the foothill plains, the driest portion of the habitat.

Shrubs are somewhat more prominent in this community than in either the red gum or blue gum country. Particularly is this so near Sedan where *Kochia georgei*, *K. brevifolia*, *Rhagodia parabolica*, *R. crassifolia*, *Cassia eremophila* var. *platypoda*, *C. sturtii* and *Acacia brachybotrya* evidently at one time formed a dense growth. For the habitat as a whole, commonly occurring shrubs and undershrubs are *Acacia armata*, *A. brachybotrya*, *Kochia brevifolia*, *Enchylaena tomentosa* and *Bursaria spinosa*. *A. pycnantha* is fairly common, while *Kochia georgei*, *Cassia sturtii*, *C. eremophila* var. *platypoda*, *Rhagodia parabolica*, *R. crassifolia*, and *Sida corrugata* are prevalent in the driest of the community. Rare are *Zygophyllum fruticulosum*, *Kochia aphylla*, *Bassia uniflora*, *Cryptandra amara* var. *longiflora*, *Hakea leucoptera*, *Acacia colletioides*, *A. spinescens*, *Dodonaea attenuata*, *Rhagodia gaudichaudiana*, *Pimelia glauca*, *Lotus australis* and *Helichrysum retusum*. *Nicotiana glauca* occurs along creeks in the foothill plains.

In the blue gum country near Keyneton there are one or two very minor occurrences of *E. odorata* on residual lateritic hills. These isolated hills have a capping of kaolinitic material containing ferruginous stainings. Associated with the peppermint gum on one such hill *Callistemon teretifolius* was recorded. This constitutes a new distribution for the species which is normally found in the southern Flinders Ranges. The parasitic *Cassytha melantha* was abundant on the *Callistemon*.

As in the blue gum community, grasses and medics form a fairly well-balanced pasture. Clovers, however, are not so prominent. *Stipa variabilis* and *Danthonia semiannularis* dominate the sward, but in the drier areas the spear grass is more prominent. Usually associated herbaceous species are *Erodium botrys*, *Vittadinia triloba* and *Hordeum leporinum*. Common species are *E. cygnorum*, *Avena fatua*, *Medicago truncatula*, *M. hispida* and *M. minima*. *Schismus barbatus*, *Erodium cicutarium*, *Enneapogon nigricans*, *Hypochaeris radicata*, *Rhagodia nutans*, *Aristida behriana*, *Anguillaria dioica* and *Bulbine bulbosa* are fairly common.

The following species are rare: *Atriplex muelleri*, *Dianella revoluta*, *Salsola kali*, *Aira caryophyllea*, *Euphorbia drummondii*, *Cryptostemma calendulaceum*, *Vulpia myuros*, *Ranunculus lappaceus*, *Helichrysum apiculatum*, *Helipterum jessenii*, *Trifolium arvense*, *T. angustifolium*, *T. tomentosum*, *Chenopodium carinatum*, *Themeda australis*, *S. eremophila*, *Trichinium spathulatum*, *Stipa elegantissima*, *Plantago lanceolata*, *Scirpus* sp., *Convolvulus erubescens*, *Bromus rigidus*, *Briza maxima*, *Lolium subulatum*, *Clematis microphylla*, *Wahlenbergia* sp., *Lepidium hyssopifolium*, *Sonchus oleraceus*, *Oxalis corniculata*, *Scleropoa rigida*, *Senecio lautus*, *Trichinium alopecuroideum*, *Dichopogon strictus*, *Erechthites quadridentata*, *Moraea xerospatha* var. *monophylla* and *Cheilanthes tenuifolia*.

Lomandra multiflora and more rarely *L. dura* occasionally give a characteristic appearance to the community by forming a layer beneath the trees.

Of the weeds, *Echium plantagineum* is again the most widespread species. Very common also are *Salvia verbenaca*, *Romulea rosea*, *Oxalis cernua* and *Onopordon acaule*. The following are rarely found: *Lycium ferocissimum*, *Solanum nigrum*, *Marrubium vulgare*, *Carthamus lanatus*, *Foeniculum vulgare*, *Onopordon acanthium*, *Inula graveolens* and *Heliotropium europaeum*.

Generally the pastures are similar to those of the blue gum country, but in the drier portions of the habitat certain changes take place. The red gum and blue gum associations contain few shrubs, and those that do occur are sclerophyllous and generally of little fodder value. In the foothill plain portion of the peppermint habitat, however, several palatable shrubs occur. These are *Kochia georgei*, *Rhagodia parabolica*, *R. crassifolia*, *Cassia sturtii*, *Enchylaena tomentosa*, *Bassia uniflora* and *Rhagodia gaudichaudiana*. Among the grasses the more drought-resistant *Stipa variabilis* becomes more prominent than *Danthonia semiannularis*. Clovers, grasses like *Bromus rigidus*, and other plants such as *Cryptostemma calendulaceum*, which are important constituents of the natural pastures of the higher rainfall country, become rare. At the same time more drought-resistant fodder plants like *Schismus barbatus* and *Erodium cygnorum* come in to take their place. *Medicago minima*, the most drought-resistant of the medics, is prominent. Species like *Enneapogon nigricans* and *Salsola kali*, which have such a wide distribution in the arid country and which grow following summer rains, become conspicuous.

These changes are seen only in the driest of the community. On the slopes of the ranges, where the rainfall is higher, the native pastures are very similar to those of the blue gum association.

(5) LOMANDRA MULTIFLORA – L. DURA association (pl. III, fig. 1).

This community has received no attention since Wood (13) mentioned its occurrence. The habitat has a rainfall of 10½″ to 18″ per annum and ranges from 1,500-3,000 feet above sea level. In these highlands frosts are common during the winter, while light falls of snow occur very infrequently. The region is rough and hilly, but the *Lomandras* also extend across the broad valleys between the ridges. Their density, however, is lower in the valleys and

the community here assumes more the characteristics of a grassland. It is difficult to say whether *Lomandra* was originally as prominent in the valleys as on the hills, but it probably was not. However, reports of the early surveyors sometimes refer to black grass or tussock grass in places where little or no *Lomandra* can be found today, but their reports generally only distinguished between arable land and stony grazing land.

The association does not occur elsewhere in the State and does not extend far beyond the northern boundary of the area mapped, but it does extend further to the west. A characteristic of the community is the general absence of trees, but there are some local occurrences of *Eucalyptus leucoxylon, E. odorata, Casuarina stricta* and *Callitris propinqua*. Where these species occur there is no change in the understorey except perhaps in its density. The treelessness of the area, which is definitely supported by early survey reports, is difficult to explain. Neither soils nor rainfall appear to be limiting factors for tree growth, since even the skeletal soils might reasonably be expected to carry sheoaks. The rare occurrences of sheoaks in the area are on such soils. It appears that the only factor which could perhaps be limiting is temperature. No difficulty, however, is experienced in growing various species of eucalypts around farm buildings in the area, but the seedlings when young are given protection which they would not receive under natural conditions.

Throughout most of the association *L. dura* and *L. multiflora* occur as co-dominants, but in the drier phases of the community *L. multiflora* occurs alone. Towards the eastern boundary of the association east of Hallett, *Cryptandra amara* var. *longiflora* is a prominent species, while *Triodia irritans* replaces *Lomandra* on one or two hills south of Burra. Associated with the *Triodia* is *Xanthorrhoea quadrangulata*.

Shrubs and undershrubs are not a prominent feature. However, in drier areas *Kochia aphylla* is frequently abundant in depressions in the valleys, while *K. georgei* is common and *K. brevifolia* rare. *Hakea leucoptera, Acacia oswaldii, A. ligulata, Lycium australe, Eremophila longifolia, Enchylaena tomentosa, Rhagodia spinescens, Cassia sturtii, C. eremophila* var. *platypoda* and *Bassia uniflora* are only found adjacent to mallee. *Nicotiana glauca* is associated with creeks in drier parts of the habitat. *Acacia victoriae* and *A. colletoides* are restricted to the country north of Whyte Yarcowie in this community. On the eastern slopes of the hills near Burra, *Nitraria schoberi* is an early colonizer of badly eroded land. In addition to the species listed above from drier localities, *Acacia spinescens, A. pycnantha, A. armata* and *Pimelia glauca* are very rare elsewhere. *Bursaria spinosa* and *Sida corrugata* are more widespread.

Herbaceous plants are the most important members of the community. *Stipa variabilis* and *Danthonia semiannularis* dominate the sward. Usually associated herbaceous species are *Vittadinia triloba, Erodium botrys, Atriplex muelleri, Stipa eremophila, Medicago hispida* and *M. minima*. Less common are *M. truncatula, Avena fatua, Helipterum jessenii, Atriplex campanulatum, Wahlenbergia* sp., *Euphorbia drummondii* and *Aristida behriana*. *Lepidium hyssopifolium, Erodium cygnorum, Enneapogon nigricans, Convolvulus erubescens* and *Hordeum leporinum* are fairly common.

The following species are rare: *Trifolium tomentosum, T. arvense, T. angustifolium, Helichrysum apiculatum, Schismus barbatus, Oxalis corniculata, Moraea xerospatha* var. *monophylla, Erechthites quadridentata, Rhagodia nutans, Bromus rigidus, Vulpia myuros, Stipa elegantissima, Bassia patenticuspis, Chenopodium carinatum, Lolium subulatum, Dichopogon strictus, Sherardia arvensis, Erodium cicutarium, Themeda australis, Cryptostemma calendulaceum, Atriplex*

semibaccatum, Dianella revoluta, Teucrium racemosum, Kochia tomentosa var. *humilis* (only recorded near Terowie), *Lotus australis, Sonchus oleraceus, Bromus madritensis, Anguillaria dioica, Blennodia trisecta, Bassia sclerolaenoides, Zygophyllum ammophilum, Lepidosperma* sp., *Hypochaeris radicata* and *Cymbopogon exaltatus* (only in creek beds).

Eucalyptus largiflorens (river box) fringes two lagoons north of Terowie. *Muehlenbeckia cunninghamii* is associated.

Widespread and common weeds are *Echium plantagineum, Carthamus lanatus* and *Onopordon acaule. Asphodelus fistulosus* is particularly common near Burra and Terowie. *Salvia verbenaca* is fairly common. Another species, *S. aethiopis*, occurs near Ulooloo.

Rare weeds are *Xanthium spinosum, Marrubium vulgare, Inula graveolens, Lycium ferocissimum, Heliotropium europaeum, Citrullus vulgaris, Cynara cardunculus, Solanum nigrum, Oxalis cernua, Sisymbrium orientale* and *Malva parviflora.*

The *Lomandra* community has a wider rainfall range than any other association in the area studied, and as a result pasture species which are important in the higher rainfall portions are frequently unimportant elsewhere and vice versa. Furthermore, the pastures vary considerably in density. In the highest rainfall areas, under judicious grazing, there is a fairly good ground cover, but north of Whyte Yarcowie the pasture is very uneven with many bare areas, associated with which are scattered surface stones.

The lists of species and their frequencies of occurrence as given above are for the association as a whole. An examination of the distributions and frequencies of the species shows that from the pasture viewpoint the area can be divided into two regions, the dividing line being approximately the 14" rainfall isohyet. This corresponds to the rainfall at which *L. dura* ceases to be as prominent as *L. multiflora.* In the region which has a 14-18" annual rainfall *Danthonia semiannularis, Stipa variabilis, Erodium botrys, Medicago hispida, M. truncatula, Stipa eremophila, Bromus rigidus, Aristida behriana, Avena fatua, Hordeum leporinum, Cryptostemma calendulaceum and Erodium cicutarium* are the most prominent species in the pasture. Less common are *Themeda australis, Salsola kali, Enneapogon nigricans* and *Atriplex muelleri. L. dura* is grazed but the harder *L. multiflora* is inedible.

In the 10½-14" rainfall region *Stipa variabilis* is more prominent than *Danthonia semiannularis;* there is much less *Medicago hispida* and *M. truncatula*, but *M. minima* tends to take their place. Medics, however, are absent in the driest of the area. Other prominent species are *Erodium botrys, E. cygnorum, Stipa eremophila, Schismus barbatus, Convolvulus erubescens* and *Rhagodia nutans. Enneapogon nigricans* and *Salsola kali* are more common, while there is less *Aristida behriana* and *Avena fatua; Atriplex campanulatum* largely replaces *A. muelleri.* Similarly, there is less *Echium plantagineum*, but in this area and all the communities where it occurs on the drier side, this plant must be regarded as a useful fodder species. *Kochia georgei* is a useful fodder shrub.

The mallee communities.

The area discussed in this paper is an ideal one for a study of the mallee communities because the associated soils are fairly uniform throughout, there is an absence of sandhills which cause local variation in soil moisture content, and the annual rainfall decreases from west to east through the habitat. A study can thus be made of the effect of variations in rainfall under comparatively uniform edaphic conditions.

Three plant associations whose dominants are eucalypts with mallee habit occur in the area. *E. anceps – E. dumosa* association is found on brown solonized soils in the 12-14½″ annual rainfall zone. With slightly lower rainfall (10½-12″) this community is replaced by one dominated by *E. brachycalyx* var. *chindoo* and *E. oleosa*. With lower rainfall *E. brachycalyx* disappears. The most xerophytic community is the *E. oleosa – E. gracilis* association which is found on brown solonized soils in the 8-10½″ annual rainfall zone.

(6) E. ANCEPS – E. DUMOSA association.

Only a few remnants remain of this association in the area studied, since most of the land formerly supporting it has been cleared for wheat-growing. Even where the dominants have not been destroyed intensive grazing has removed the associated species. The habitat is characterised by brown solonized soils which, on account of slightly higher rainfall, contain less lime and are of greater depth than the soils carrying the other two mallee communities.

Occasional trees of *Myoporum platycarpum*, *Callitris propinqua*, and *Eucarya* sp. are scattered through the mallee, while *Pittosporum phillyreoides* and *Heterodendron oleifolium* are very rare.

It is in the mallee and drier communities that shrubs become really important constituents of the vegetation. Sclerophyllous shrubs are an important element in the sclerophyll forest formations of the Mount Lofty Ranges, but the high rainfall communities in the area being discussed in this paper are essentially savannah woodlands in which shrubs are of rare occurrence.

The following shrubs and undershrubs are common: *Rhagodia parabolica*, *Acacia brachybotrya*, *Enchylaena tomentosa*, *Cassia sturtii*, *C. eremophila* var. *platypoda*, *Bassia uniflora*, *Kochia brevifolia*, *Melaleuca pubescens*, *Dodonaea attenuata*, *Kochia georgei* and *Cassia eremophila*. Fairly common are *Acacia colletoides*, *Westringia rigida*, *Zygophyllum fruticulosum* and *Rhagodia crassifolia*, while *Grevillea huegelii*, *R. spinescens*, *R. gaudichaudiana*, *Sida corrugata*, *Eremophila longifolia* and *Acacia oswaldii* are fairly rare. Rare are *Kochia aphylla*, *Bassia parviflora*, *Acacia calamifolia*, *A. ligulata*, *A. notabilis*, *Olearia floribunda*, *Bursaria spinosa*, *Eremophila divaricata* and *Atriplex rhagodioides*. *Muehlenbeckia cunninghamii* grows in swamps.

Dominant herbaceous species are *Stipa variabilis and Schismus barbatus*. Usually associated herbaceous species are *Danthonia semiannularis*, *Medicago minima* and *M. hispida*. *Salsola kali*, *Atriplex muelleri* and *Vittadinia triloba* are commonly occurring plants, while *Erodium botrys*, *Rhagodia nutans*, *Hordeum leporinum*, *Convolvulus erubescens*, *Sisymbrium orientale* and *Erodium cygnorum* are less common. Rare are *Wahlenbergia* sp., *Stipa elegantissima*, *Euphorbia drummondii*, *Oxalis corniculata*, *Avena fatua*, *Lomandra multiflora*, *Teucrium racemosum*, *Anguillaria dioica*, *Cryptostemma calendulaceum*, *Enneapogon nigricans*, *Medicago truncalata*, *Lepidium hyssopifolium*, *Dianella revoluta*, *Trichinium spathulatum*, *Helichrysum apiculatum*, *Cynodon dactylon*, *Nicotiana* sp., *Atriplex semibaccatum*, *A. campanulatum*, *Echium plantagineum* and *Bassia sclerolaenoides*.

Cassytha melantha is parasitic on mallees and shrubs.

The following weeds occur in the community: *Onopordon acaule* is common; *Heliotropium europaeum*, *Salvia verbenaca*, *Citrullus vulgaris*, *Lycium ferocissimum*, *Inula graveolens*, *Reseda luteola*, *Oxalis cernua*, *Carthamus lanatus* and *Foeniculum vulgare* are rare.

Of the eleven common shrubs present in the community, five are good fodder species. These are *Cassia sturtii*, *Kochia georgei*, *Rhagodia parabolica*, *Enchylaena tomentosa* and *Bassia uniflora*. *C. sturtii*, *K. georgei* and *B. uniflora*

are among the most palatable of the *Cassias*, bluebushes and bindyis respectively. *Dodonaea attenuata* is grazed to some extent but is not important. *Kochia brevifolia* is unpalatable and very rarely grazed. *Melaleuca pubescens* and *Acacia brachybotrya* are not grazed.

Rhagodia crassifolia is the only useful species among the four fairly common shrubs. *Westringia rigida* and *Acacia colletoides* are grazed to some extent but are not significant. (Species like *D. attenuata* and *A. colletoides* are liable to be grazed slightly when sheep are sheltering among them. They are often eaten up to the height the sheep can reach.)

Both dominant grasses are good fodder species, *Stipa variabilis* germinating with summer rains, while *Schismus barbatus* comes away quickly with winter rains but soon dries up with any hot weather. Of the three usually associated herbaceous species, *Danthonia semiannularis* and *Medicago hispida* are important. *M. minima* is less valuable, since it does not produce as much edible growth as *M. hispida*. The summer growing *Salsola kali* and the winter growing *Atriplex muelleri* are useful fodder plants among the common species. *Vittadinia triloba*, however, is very rarely grazed. All the less common species are useful fodder plants, the annuals, *Erodium botrys*, *E. cygnorum*, *Hordeum leporinum*, and *Sisymbrium orientale* growing with winter rains.

(7) Eucalyptus oleosa – E. brachycalyx association.

The dominants of this community are *E. oleosa* and *E. brachycalyx* var. *chindoo*. *E. gracilis* is commonly present as a codominant. The habitat is level to undulating and is characterised by brown solonized soils.

Occasional trees of *Myoporum platycarpum*, and very rarely *Heterodendron oleifolium*, *Callitris propinqua*, *Pittosporum phillyreoides* and *Eucarya* sp. are scattered through the mallee.

Shrubs and undershrubs are conspicuous in portions of the habitat and practically absent elsewhere, depending upon the density of the dominants. *Atriplex stipitatum* is common in the southern part, while further north, in County Burra, *A. vesicarium* and *A. stipitatum* may occur together (pl. III, fig. 2).

Other common species are *Bassia uniflora*, *Kochia brevifolia*, *K. tomentosa*, *Enchylaena tomentosa* and *Zygophyllum fruticulosum*. Fairly common are *Z. glaucescens*, *Myoporum deserti*, *Rhagodia spinescens*, *R. gaudichaudiana*, *Olearia muelleri* and *Cassia sturtii*, while *Kochia georgei*, *K. triptera*, *Grevillea huegelii*, *Westringia rigida*, *Acacia colletoides*, *Exocarpus aphylla*, *Melaleuca pubescens*, *Bassia parviflora* and *Dodonaea attenuata* are fairly rare. The following species are rare: *Eremophila scoparia*, *E. longifolia*, *Rhagodia parabolica*, *Kochia sedifolia*, *K. aphylla*, *Acacia oswaldii*, *A. brachybotrya*, *A. notabilis*, *A. microcarpa*, *Sida corrugata*, *Templetonia egena*, *Cassia eremophila*, *C. eremophila* var. *platypoda*, *Atriplex rhagodioides*, *Nitraria schoberi*, *Rhagodia crassifolia*, *Kochia tomentosa* var. *apressa*, *Acacia calamifolia*, *Hakea leucoptera* and *Eremophila glabra*. *Bursaria spinosa* and *Kochia pyramidata* are very rare. *Nicotiana glauca* occurs along creeks and swamps.

The parasitic *Cassytha melantha* is rarely found on the eucalypts.

Dominant herbaceous plants are *Stipa variabilis*, *Schismus barbatus*, *Bassia sclerolaenoides*, *Atriplex campanulatum* and *Zygophyllum ammophilum*. *Bassia decurrens* and *Salsola kali* are usually associated. *Erodium cygnorum*, *Tetragonia expansa*, *E. botrys* and *Zygophyllum crenatum* are fairly rare. Rare are *Danthonia semiannularis*, *Vittadinia triloba*, *Atriplex spongiosum*, *A. semibaccatum*, *A. muelleri*, *Medicago minima*, *M. hispida*, *M. truncatula*, *Mesembryanthemum crystallinum*, *Hordeum leporinum*, *Cryptostemma calendulaceum*, *Stipa elegantissima*, *Rhagodia nutans*, *Vulpia myuros*, *Lepidium hyssopifolium*, *Echium*

plantagineum, Sisymbrium orientale, Enneapogon nigricans, Euphorbia drummondii, Dianella revoluta, Teucrium racemosum, Chenopodium desertorum, Ch. microphyllum and *Trichinium spathulatum*.

Of the weeds *Citrullus vulgaris, Onopordon acaule, Heliotropium europaeum* and *Carthamus lanatus* are common. The following are occasionally found: *Inula graveolens, Romulea rosea, Marrubium vulgare, Reseda luteola, Salvia verbenaca, Oxalis cernua* and *Lycium ferocissimum*.

Eucalyptus largiflorens fringes some swamps which occur near Sedan.

Four of the seven common shrubs are useful fodder species: *Bassia uniflora, Enchylaena tomentosa, Atriplex vesicarium* and *Kochia tomentosa*. *A. stipitatum* is unpalatable and practically useless. *Zygophyllum fruticulosum* may be grazed occasionally but is unimportant. *Cassia sturtii, Rhagodia gaudichaudiana, R. spinescens* are the only useful fairly common shrubs. *Olearia muelleri* and more particularly *Myoporum deserti* are grazed to some extent but are not important. *Zygophyllum glaucescens* is never under any circumstances grazed.

Stipa variabilis, Schismus barbatus, Bassia sclerolaenoides and *Atriplex campanulatum* are the most important of the dominant herbaceous species. *Zygophyllum ammophilum* is not grazed. Of the usually associated species *Salsola kali* is a useful plant. *Bassia decurrens* is of value when young. *Tetragonia expansa, Erodium botrys* and *E. cygnorum*, all winter-growing species, are fodder plants. *Zygophyllum crenatum* is valueless.

(8) E. OLEOSA—E. GRACILIS association (pl. III, fig. 3).

The habitat is characterised by level plains or gently undulating country with brown solonized soils. North of Burra the association is found on lower slopes of hills and in the broad valleys between the ranges. Portions of the valley bottoms, however, are liable to occasional inundation following heavy rains, and here the mallee is replaced by *Kochia aphylla* and *Acacia victoriae* shrublands. On the very shallow brown solonized soils along the River Murray, from Swan Reach to Morgan, mallee is replaced by sandalwood (*Myoporum platycarpum*) and bluebush (*Kochia sedifolia*). This is due to edaphic aridity. Further south, at Tailem Bend, Jessup (7) has shown that mallee-habit eucalypts are replaced by *Casuarina stricta* on shallow soils similar to those in the Swan Reach-Morgan area. These shallow soils are considered by Crocker (3) to have had their sandy A horizons stripped off in a recent arid period.

E. oleosa and *E. gracilis* occur as codominants, although where limestone is near the surface *E. gracilis* is perhaps more prominent. Both species are about equally drought-resistant, relic occurrences being found in the arid north-east of South Australia. The cap on the receptacle of *E. oleosa* may be either long and tapered into a beak or shortly and bluntly conical. Maiden called the tapered form *E. transcontinentalis*. However, all gradations occur from the bluntly conical to the tapered cap and there is no ecological basis for subdivision into two species. In this paper, therefore, all forms are designated as *E. oleosa*.

The density of the dominants varies considerably, and this affects the prevalence of shrubs. Towards the shallow soil zone along the River Murray the eucalypts are somewhat scattered. Here shrubs are particularly prominent.

In addition to the mallees the following small trees occur: *Myoporum platycarpum* and more rarely *Callitris propinqua, C. glauca, Heterodendron oleifolium, Eucarya* sp., and *Pittosporum phillyreoides*. *C. glauca* is found only in County Kimberley in the region discussed in this paper and does not occur south of Hallett.

North of the Eudunda-Morgan railway line *Atriplex vesicarium* is prominent in the shrub layer and in parts forms a continuous understorey. This is par-

ticularly so on parts of Tuilkilky, Pandappa and Ketchowla stations. Further south *A. vesicarium* is replaced by *A. stipitatum*. In the Sutherlands-Mount Mary area *Kochia sedifolia* is prominent. Other common shrubs and undershrubs are *Zygophyllum glaucescens, Myoporum deserti, Acacia colletioides, Bassia uniflora, Kochia brevifolia* and *K. triptera*.

Fairly common are *Templetonia egena, K. tomentosa, K. tomentosa* var. *appressa, Zygophyllum fruticulosum, Enchylaena tomentosa, Rhagodia spinescens, R. gaudichaudiana, Cratystylis conocephala, Atriplex rhagodioides, Exocarpus aphylla, Eremophila scoparia, Olearia muelleri, Lycium australe* and *Chenopodium nitrariaceum* (small-leafed form). *Grevillea huegelii, Acacia oswaldii, Cassia sturtii, C. eremophila* and *C. eremophila* var. *platypoda, Westringia rigida* and *Bassia parviflora* are fairly rare. Rare shrubs and undershrubs are *Nitraria schoberi, Sida corrugata, S. intricata, Hakea leucoptera, Dodonaea attenuata, Eremophila longifolia, E. glabra, E. opposotifolia, Beyeria leschenaultii, Melaleuca pubescens, Kochia pyramidata, Acacia notabilis, A. ligulata, K. georgei* and *Rhagodia crassifolia*.

Nicotiana glauca, and more rarely *Kochia aphylla, Muehlenbeckia cunninghamii* and *Chenopodium nitrariaceum* are found in depressions liable to periodical flooding. The following species have a limited distribution: *Olearia pimeleoides, Acacia victoriae, A. calamifolia, Codonocarpus pyramidalis, Solanum ellipticum, Trichinium obovatum, Eremophila alternifolia* and *Lepidium leptopetalum*. Of these species *C. pyramidalis, E. alternifolia, S. ellipticum, T. obovatum*, and *A. victoriae* are found only in the far north of the habitat, the latter along watercourses. *Olearia pimeleoides* was only recorded east of Terowie. *Lepidium leptopetalum* is very common south of Morgan.

Dominant herbaceous species are *Bassia decurrens, B. sclerolaenoides, Stipa variabilis* and *Zygophyllum ammophilum*. Usually associated herbaceous species are *Atriplex campanulatum, Schismus barbatus* and *Salsola kali*, while *Zygophyllum crenatum, Erodium cygnorum, Tetragonia expansa, Chenopodium desertorum* and *Ch. microphyllum* are fairly common.

The following species are rare: the three medics *Medicago minima, M. hispida* and *M. truncatula* which are found only in depressions, *Erodium botrys, Atriplex muelleri, A. limbatum, A. velutinellum, A. angulatum, Bassia paradoxa, Danthonia semiannularis, Blennodia cardaminoides, B. trisecta, E. cicutarium, Bassia brachyptera, Ch. cristatum, Babbagia acroptera, Tragus australianus, Enneapogon nigricans, Bassia patenticuspis, Dianella revoluta, Stipa elegantissima, Eragrostis dielsii, Euphorbia drummondii, Lotus australis* var. *parviflorus, Lepidium hyssopifolium, Mesembryanthemum crystallinum, Atriplex semibaccatum, Goodenia cycloptera, A. spongiosum* and *Sisymbrium orientale. Cymbopogon exaltatus* grows in creek beds.

Additional herbaceous species which are found in country occasionally inundated are *Bromus rigidus, Teucrium racemosum, Sherardia arvensis, Paspalidium gracile, Erechthites quadridentata, Nicotiana* sp., *Vittadinia triloba, Polygonum aviculare, Echium plantagineum, Sonchus oleraceus, Malva parviflora, Convolvulus erubescens, Rhagodia nutans, Oxalis corniculata, Wahlenbergia* sp. and *Hordeum leporinum*.

Weeds which are found in the area are *Marrubium vulgare, Inula graveolens, Asphodelus fistulosus, Solanum nigrum, Lycium ferocissimum, Carthamus lanatus, Reseda luteola, Centaurea solstitialis, C. calitrapa, Salvia verbenaca, Heliotropium europaeum, Citrullus vulgaris* and *Xanthium spinosum. Carrichtera annua* was found along the railway line at Morgan. Many of the weeds occur principally in depressions which are liable to flooding.

Only three of the nine common shrubs are useful fodder species: *Bassia uniflora, Atriplex vesicarium* and *Kochia sedifolia*. *K. triptera* is unpalatable and never under any circumstances grazed. Six of the 14 species of fairly common shrubs are useful plants: *Enchylaena tomentosa, K. tomentosa, Cratystylis conocephala, K. tomentosa* var. *appressa, Rhagodia gaudichaudiana* and *R. spinescens*. *Templetonia egena, Eremophila scoparia, Exocarpus aphylla* and *Chenopodium nitrariaceum* (small-leafed variety) are grazed to some extent but are not important. *Lycium australe* is similarly practically valueless. *Cratystylis conocephala*, which so much resembles *Kochia sedifolia* in general appearance, is not as resistant to grazing as the true bluebush.

The only really important fodder plants among the dominant herbaceous species are *Stipa variabilis* and *B. sclerolaenoides*, while *Atriplex campanulatum*, *Schismus barbatus* and *Salsola kali*, the usually associated species, are all useful plants. Insufficient evidence was accumulated on *Chenopodium desertorum* and *Ch. microphyllum* to enable their palatabilities to be assessed.

These stony mallee areas, which are unsuited to cultivation, produce more valuable fodder shrubs than the sandy mallee. The herbaceous species, too, are more persistent on the stony areas, which are therefore better adapted to grazing than the sandy mallee.

(9) EREMOPHILA – DODONAEA – ACACIA association (pl. III, fig. 4).

On the rugged hills north of Burra *E. oleosa – E. gracilis* association is only found on the lower slopes of the hills and in the valleys between the ridges. The hills themselves are almost entirely without mallee but carry shrublands in which the dominants are species of *Eremophila, Dodonaea* and *Acacia*. Wood (13) first described the shrubland association.

Dodonaea lobulata, D. attenuata, Eremophila serrulata, E. alternifolia, Acacia calamifolia and *A. acinacea* are the dominant species, growing to a height of about six feet. *Triodia irritans* is dominant on parts of the Pitcairn Range. *Rhagodia parabolica* is also prominent. Fairly commonly associated shrubs and undershrubs are *Bassia uniflora, Trichinium obovatum, Kochia brevifolia, Acacia pycnantha* and *Zygophyllum glaucescens*. Rare are *Sida corrugata, Bursaria spinosa, Helichrysum retusum, Eremophila opposotifolia, Cassia eremophila, C. eremophila* var. *platypoda, C. artemesioides, C. sturtii, Enchylaena tomentosa, Sida petrophila, Kochia tomentosa* var. *appressa, Rhagodia gaudichaudiana, R. spinescens, Solanum ellipticum, Codonocarpus pyramidalis* and *Acacia notabilis*. The following species are very rare: *Kochia georgei, Hakea leucoptera, Eremophila longifolia* and *Nicotiana glauca*.

Callitris glauca, and more rarely *Heterodendron oleifolium, Pittosporum phillyreoides* and *Eucarya* sp. are small trees of occasional occurrence.

Rock outcrops are widespread but in soil pockets the following herbaceous species are common: *Stipa variabilis, Erodium cygnorum, Danthonia semiannularis* and *Atriplex campanulatum*. Fairly common are *Vittadinia triloba, Euphorbia drummondii, Erechthites quadridentata, Oxalis corniculata* and *Bassia patenticuspis*. *Schismus barbatus, Rhagodia nutans, Salsola kali, Medicago minima, M. hispida, Wahlenbergia* sp. and *Tetragonia expansa* are fairly rare. Rare are *Atriplex muelleri, Bromus rigidus, Stipa elegantissima, Echium plantagineum, Chenopodium cristatum, Aristida behriana, Enneapogon nigricans, Lomandra dura, L. multiflora, Zygophyllum crenatum, Convolvulus erubescens, Nicotiana* sp., *Erodium cicutarium, Medicago truncatula, Sonchus oleraceus, Goodenia cycloptera, Trichinium spathulatum* and *Stipa eremophila*.

Carthamus lanatus and *Heliotropium europaeum* are the only weeds.

This community contains few valuable fodder species. *Rhagodia parabolica*, which is not widespread but is only a dominant species in restricted localities, is the only valuable shrub among the dominants. The grain of *Triodia irritans* (porcupine grass) is eaten readily by sheep but is only produced in good years when there is a supply of herbage and grass. Some of the other dominants are grazed slightly, but none are important. *Trichinium obovatum* and *Bassia uniflora* are the only useful species among the five fairly common shrubs and undershrubs. The palatable *Cassias* appear to have been more common prior to grazing.

Much of the area is wasteland, herbaceous species being confined to shallow soil pockets. The four common herbaceous plants—*Stipa variabilis, Danthonia semiannularis, Erodium cygnorum* and *Atriplex campanulatum* are valuable fodder species. *Bassia patenticuspis* is the only useful plant among the five fairly common herbaceous species, *Oxalis corniculata, Erechthites quadridentata, Vittadinia triloba* and the poisonous *Euphorbia drummondii* being of no value.

(10) Myoporum platycarpum—Kochia sedifolia association (pl. IV, fig. 1).

In South Australia, where the rainfall exceeds 8" per annum, the dominant trees are usually species belonging to the genus *Eucalyptus*, but in the more arid regions trees belonging to other genera become the dominants. *M. platycarpum* (sandalwood), which in the mallee is only of occasional occurrence, is the dominant tree over a considerable portion of the north-east of the State. Associated widely with it as an understorey is the saltbush (*Atriplex vesicarium*), but on rising ground where limestone is near the surface of the soil bluebush (*Kochia sedifolia*) replaces the saltbush. However, in the area discussed in this paper the habitat is characterised by soils in which lime occurs at shallow depth, so that bluebush is the shrub dominant, saltbush being found principally in watercourses. The transition from bluebush to saltbush dominant communities occurs near the northern boundary of the area surveyed, the first saltbush country being on Pitcairn Station.

The occurrence of *K. sedifolia* as far south as Blanchetown and Swan Reach makes this the southern-most occurrence of any bluebush dominant community in this State.

Heterodendron oleifolium is fairly common, while *Eucarya* sp. and *Pittosporum phillyreoides* are rarely found. The shrub layer is almost a monospecific community of bluebush, other shrubs and undershrubs being comparatively rarely found. However, *Sida corrugata, S. intricata,* and *Chenopodium nitrariaceum* (small-leafed form) are fairly common. Rare are *Bassia obliquicuspis, Enchylaena tomentosa, Kochia tomentosa* var. *appressa, Rhagodia spinescens, R. gaudichaudiana, Cassia eremophila, C. eremophila* var. *platypoda, C. sturtii, Acacia oswaldii, Kochia georgei, Lycium australe, Exocarpus aphylla, Hakea leucoptera, Eremophila scoparia, E. longifolia, Bassia tricuspis,* and on shallow soils among rock outcrops *Sida petrophila, Trichinium obovatum* and *Eremophila alternifolia. Bassia uniflora* is only found adjacent to mallee. *Eremophila sturtii* is very rare in the northern part of the habitat. Shrubs which are conspicuous in the Morgan-Blanchetown area but which are rare elsewhere in this association are *Acacia colletoides, Templetonia egena* and *Myoporum deserti.*

In addition to *Atriplex vesicarium,* shrubs and undershrubs typical of watercourses are *Kochia pyramidata, K. brevifolia, Solanum ellipticum, Nicotiana glauca, Acacia victoriae* (rare in north and absent in south) and *Nitraria schoberi. Muehlenbeckia cunninghamii, Eremophila glabra, E. maculata, Kochia aphylla* and *Chenopodium nitrariaceum* are found in areas liable to flooding.

Dominant herbaceous species are *Stipa nitida* and *Bassia patenticuspis.* Usually associated are *Tetragonia expansa, Schismus barbatus* (particularly on

sand accumulations), *Salsola kali, Zygophyllum ammophilum* and *Bassia sclerolaenoides*, while *Atriplex campanulatum, Lotus australis* var. *parviflorus, Erodium cygnorum* and *Zygophyllum crenatum* are fairly common, and *Z. iodocarpum, Euphorbia drummondii* and *Bassia decurrens* are fairly rare.

Rare are *Atriplex vellutinellum, A. angulatum, Craspedia pleiocephala, Bassia brachyptera, B. paradoxa, Erodium cicutarium, Babbagia acroptera, Enneapogon nigricans, Stenopetalum lineare, Trichinium spathulatum, Dactyloctenium radulans, Tribulus terrestris, Tragus australianus, Chenopodium cristatum, Euphorbia eremophila* and *Atriplex limbatum*. Herbaceous plants typical of watercourses and depressions are *Convolvulus erubescens, Nicotiana sp., Erechthites quadridentata, Eragrostis dielsii, Blennodia trisecta, Stipa eremophila, Teucrium racemosum, Goodenia cycloptera, Marsilea drummondii, Trigonella suavissima, Stipa elegantissima, Lepidium fasciculatum, Paspalidium gracile, Medicago hispida, M. minima, Danthonia semiannularis, Vittadinia triloba, Malva parviflora, Lepidium hyssopifolium, Lavatera plebeja, Chloris truncata, Sonchus oleraceus, Wahlenbergia* sp., *Rhagodia nutans, Oxalis corniculata, Echium plantagineum, Polygonum aviculare, Atriplex spongiosum* and in creek beds *Cymbopogon exaltatus*.

Xanthium spinosum is the worst weed occurring in the pastoral country of South Australia. It completely takes charge of watercourses following summer rains. *Asphodelus fistulosus*, although not of wide occurrence, is another bad weed in watercourses. The following weeds are found principally in watercourses but are relatively unimportant: *Citrullus vulgaris, Heliotropium europaeum, Carthamus lanatus, Onopordon acaule, Inula graveolens, Marrubium vulgare* and *Romulea rosea*.

With the possible exception of *Casuarina stricta* (sheoak) the dominant species of the previously discussed associations have no fodder value. However, the foliage of *Myporum platycarpum* and also *Heterodendron oleifolium* is pulled during drought periods for sheep feed. Bluebush is an excellent drought reserve, but is not grazed to any extent when more palatable herbaceous feed is available. During good seasons, therefore, no damage is done to the bush cover by increasing the stocking rate above the carrying capacity of the average years. Saltbush is more palatable than bluebush, but again is not grazed extensively when grass and herbage are available. *Kochia pyramidata* (black bluebush) is of no value. *Sida intricata* is a useful species, but *S. corrugata* and *Chenopodium nitrariaceum* (small-leafed form), while grazed to some extent, are not important.

Apart from *A. vesicarium*, of the shrubs found in watercourses *Acacia victoriae*, which is of rare occurrence in this area, is the only edible species. *Kochia brevifolia, Solanum ellipticum, Nicotiana glauca and Nitraria schoberi* are not grazed. *Chenopodium nitrariaceum* is the most useful shrub found in country liable to flooding.

Although the species of *Bassia* which are found in the area are small undershrubs, they are regarded as herbage by graziers and are best considered with the herbaceous species. *Stipa nitida* and *Bassia patenticuspis* are the most important herbaceous plants. The winter growing *Schismus barbatus* and *Tetragonia expansa* and the summer growing *Salsola kali* are important associated species. *Zygophyllum ammophilum* is not grazed but *Bassia sclerolaenoides* is of value. *Z. ammophilum, Z. iodocarpum* and *Z. crenatum* all grow following winter rains. Valuable fairly common species are *Atriplex campanulatum* and *Erodium cygnorum*. *Zygophyllum crenatum* and the poisonous *Lotus australis* var. *parviflorus* are of no value. It is significant that *Lotus* is spreading in the pastoral country, since it is an early colonizer of eroded soils.

Watercourses are the most valuable portion of the country to the grazier, since here any rains which fall have their most beneficial effect and the species growing there are among the most valuable fodder plants. The presence of watercourses in the north-east of the State is largely responsible for the higher carrying capacity compared with the north-west. Unfortunately, however, the carrying capacity of the watercourse is so much greater than the adjacent country in the same paddock that the areas around heavily stocked but not overstocked watercourses are invariably eaten out.

Of the plants restricted to watercourses the following are among the most valuable fodder plants: *Medicago hispida*, *M. minima*, *Danthonia semiannularis*, *Trigonella suavissima*, *Convolvulus erubescens*, *Chloris truncata*, *Paspalidium gracile*, *Eragrostis dielsii*, *Sonchus oleraceus*, *Lavatera plebeja*, *Stipa elegantissima*, *Echium plantagineum*, *Goodenia cycloptera*, *Rhagodia nutans*, *Atriplex spongiosum* and *Stipa eremophila*. Of no value are *Wahlenbergia* sp., *Nicotiana* sp., *Erechthites quadridentata*, *Blennodia trisecta*, *Teucrium racemosum*, *Lepidium fasciculatum*, *Vittadinia triloba* and *Oxalis corniculata*. *Polygonum aviculare* is very rarely found. Data concerning *Marsilea drummondii* were conflicting. Many other species which are not limited to watercourses are also, of course, present.

Apart from the deleterious effects of the fruiting bodies of plants like *Xanthium spinosum* in the wool of sheep, the most serious aspect of the growth of weeds in watercourses is their crowding out of valuable fodder species.

On Braemar and adjoining stations in the area carrying *M. platycarpum*–*K. sedifolia* association there are three or four isolated hills with very small patches (usually only a few trees) of mulga (*Acacia aneura* and *A. aneura* var. *latifolia*). These are the southernmost outliers of the mulga communities which are found on hills in the north-east of the State. *Atriplex vesicarium* grows in the soil pockets with the mulga, and also, more rarely, *Eremophila alternifolia*. Characteristic herbaceous plants are species like *Paspalidium gracile*, *Oxalis corniculata*, *Convolvulus erubescens*, *Tetragonia expansa*, *Bassia patenticuspis*, *Stipa variabilis*, *Danthonia semiannularis*, *Euphorbia drummondii* and *Erodium cygnorum*, some of which on the plains only grow in watercourses. *Notholaena brownii* is common.

(11) Casuarina lepidophloia association (pl. IV, fig. 2).

This plant community has not previously been recorded in South Australia, although Beadle (1) has described a similar association in New South Wales where *Heterodendron oleifolium* is a codominant. In South Australia *H. oleifolium* is more prominent with black oak along the New South Wales border on sandier soils than those supporting black oak in the area described in this paper. Isolated societies of black oak are found throughout many of the plant communities in the arid areas of South Australia.

The habitat consists of level plains characterised by desert loams and brown solonized soils.

Black oak varies considerably in density but where is reaches its maximum development it forms a dense scrub, becoming more open towards the limits of its range with scattered clumps of very depauperate black oak interspersed with open areas of *Kochia sedifolia*, associated with which is usually *Myoporum platycarpum*. This very open country has not been mapped as black oak association. Throughout the habitat *K. sedifolia* dominates the understorey, but on the less calcareous soils its place is taken by *K. planifolia* and *Atriplex vesicarium*. In watercourses, where the soil invariably contains very little lime, *K. sedifolia* is replaced by *K. planifolia*, and, in the centre of the watercourses, *A. vesicarium*.

Heterodendron oleifolium and *Eucarya* sp. are of fairly common occurrence. *Pittosporum phillyreoides* is very rare. Common associated shrubs and undershrubs are *Rhagodia spinescens, R. gaudichaudiana, Kochia tomentosa* and *Enchylaena tomentosa.* Fairly common are *Sida intricata, S. corrugata, Templetonia egena, Exocarpus aphylla, Cassia sturtii, Chenopodium nitrariaceum* (small-leafed form) and *Zygophyllum fruticulosum,* while *Kochia georgei, Acacia colletioides* and *Eremophila scoparia* are fairly rare.

The following species are rare: *E. longifolia, E. opposotifolia, E. sturtii, Acacia oswaldii, Atriplex stipitatum, Myoporum deserti, Hakea leucoptera, Bassia tricuspis, B. uniflora, Cassia eremophila, C. eremophila* var. *platypoda, Eremophila glabra, Kochia tomentosa* var. *appressa* and *Bassia obliquicuspis. Sida petrophila, Trichinium obovatum* and *Eremophila alternifolia,* which are limited to stony rises, and *Dodonaea attenuata* and *K. tomentosa* var. *tenuifolia* are very rare.

Shrub species which although not necessarily restricted to watercourses show maximum development there are: *Kochia pyramidata, K. brevifolia, Nitraria schoberi, Nicotiana glauca, Solanum ellipticum* and *Acacia victoriae.* Found in local depressions rather than watercourses are *Kochia aphylla, Muehlenbeckia cunninghamii, Chenopodium nitrariaceum, Eremophila maculata* and *Lycium australe.*

Dominant herbaceous species are *Stipa nitida, Bassia patenticuspis* and *B. sclerolaenoides.* Usually associated are *Salsola kali, Zygophyllum ammophilum, Tetragonia expansa, Atriplex campanulatum* and *Erodium cygnorum. Lotus australis* var. *parviflorus* and *Bassia decurrens* are fairly rare. Rare are *Euphorbia drummondii, Schismus barbatus, Euphorbia eremophila, Bassia brachyptera, B. paradoxa, Stenopetalum lineare, Enneapogon nigricans, Tribulus terrestris, Atriplex vellutinellum, A. angulatum, A. limbatum, Zygophyllum iodocarpum, Erodium cicutarium, Babbagia acroptera, Dactyloctenium radulans, Tragus australianus* and *Chenopodium cristatum.*

The following herbaceous species are typical of local depressions and watercourses: *Erodiophyllum elderi, Blennodia trisecta, Vittadinia triloba, Erechtites quadridentata, Marsilea drummondii, Nicotiana* sp., *Convolvulus erubescens, Oxalis corniculata, Danthonia semiannularis, Lepidium hyssopifolium, Medicago hispida, M. minima, Wahlenbergia* sp., *Trichinium alopecuroideum* var. *rubriflorum, Paspalidium gracile, Stipa elegantissima, Atriplex spongiosum, Teucrium racemosum, Goodenia cycloptera, Eragrostis dielsii, Trigonella suavissima, Malva parviflora, Sonchus oleraceus, Lavatera plebeja, Chloris truncata* and *Echium plantagineum.*

Xanthium spinosum, Heliotropium europaeum, Citrullus vulgaris, Inula graveolens, Marrubium vulgara and *Solanum nigrum* are weeds found in watercourses. In the southern-most black oak country near Morgan, *Reseda luteola* occurs in watercourses.

The branchlets of *Casuarina lepidophloia* are eaten by stock and the species may be of some value as a fodder. Bullock bush and sandalwood have previously been discussed. Foliage of *Eucarya* and *Pittosporum phillyreoides* is grazed. *Kochia planifolia* is considerably more palatable than *K. sedifolia.* All of the common shrubs and undershrubs—*Rhagodia spinescens, R. gaudichaudiana, K. tomentosa* and *Enchylaena tomentosa* are useful fodder plants. Of the fairly common species *Cassia sturtii* and *Sida intricata* are palatable. *S. corrugata, Templetonia egena, Exocarpus aphylla, Zygophyllum fruticulosum* and *Chenopodium nitrariaceum* (small-leafed form) are grazed to some extent but are not important. *K. georgei,* a fairly rare species here, is perhaps the most palatable of the *Kochias. Acacia victoriae* is the only edible species among those found

principally in watercourses. *Chenopodium nitrariaceum* is the only species grazed among the shrubs found in depressions.

Stipa nitida, *B. sclerolaenoides* and *Bassia patenticuspis* are the most important of the herbaceous species. *Zygophyllum ammophilum* is the only useless plant among the usually associated herbaceous species. Of the watercourse plants the following are useful: *Convolvulus erubescens*, *Medicago hispida*, *M. minima*, *Trichinium alopecuroideum* var. *rubriflorum*, *Paspalidium gracile*, *Stipa elegantissima*, *Atriplex spongiosum*, *Goodenia cycloptera*, *Eragrostis dielsii*, *Trigonella suavissima*, *Sonchus oleraceus*, *Lavatera plebeja*, *Chloris truncata*, *Danthonia semiannularis* and *Echium plantagineum*.

Effects of Overgrazing the Arid Plant Communities

When stock are introduced into any country the plants are naturally consumed in their order of palatability. The most palatable species are consumed first, and unless the country is stocked judiciously eventually only the unpalatable plants remain. Frequently the unpalatability takes the form of spine development, excessive hairiness or the accumulation in the leaves of unpalatable chemical substances. Young plants of mulga and sandalwood growing during drought times when little or no fresh growth is made are not eaten by sheep.

A similar formation of unpalatable chemical substances must be the cause of the inedibility of plants like *Kochia triptera*, *Zygophyllum apiculatum*, *Z. ammophilum*, etc. However, in heavily stocked country the very survival of the plants depends upon some quality which protects them from the grazing animal.

Through the black oak and sandalwood-bluebush country, the principal fodder shrub is the bluebush (*K. sedifolia*). The floristic composition of the pastures has almost certainly been greatly modified by stocking. Areas which now are almost pure shrublands of bluebush probably at one time carried other more palatable shrub species. It is now impossible to assess the original composition of the pastures, but there is ample evidence that *Cassias* were at one time far more common. The dead sticks of these species are found where few living plants remain, and areas from which sheep are excluded often produce a dense growth of *Cassia*.

As a result of competition for moisture, unthinned stands of bluebush rarely contain much herbage and grass. Grazing, with resultant reduction in the density of the bush, causes the appearance of bindyis, principally *Bassia patenticuspis* following winter rains, and spear grass (*Stipa nitida*) following summer rains. Eventually overgrazing results in complete destruction of the bluebush (pl. IV, fig. 3). The land has then lost its protective cover and the rate of soil loss is greatly increased. On the sandy loam and loam soils overlying heavier textured subsoils, loss of the surface soil brings about serious consequences. The exposed subsoil does not readily absorb water and constitutes a very poor seed bed (pl. IV, fig. 4). Formation of gutters on sloping land results from the lack of plant cover and the increased rate of run-off of water, much of which is now lost by evaporation from swamps into which the watercourses drain. The bindyi and spear grass lack the permanency and drought-resistance of the bluebush. Heavy winds and the blasting action of wind-borne soil particles are capable of destroying the patchy ground cover of herbaceous species in surprisingly short time.

On the scalded areas the most important pioneer plant is *Sida intricata*. As has already been pointed out, the poisonous *Lotus* is also an early colonizer on bare areas. The inedible *Nitraria schoberi* is likewise spreading on exposed subsoils in the north-east of the State. This species normally grows in somewhat

saline watercourses and swamps and its spread on the eroded areas is due to the somewhat higher salinity of the subsoils as compared with the surface soils. In some areas *Nitraria* has completely taken charge, and by its spreading habit of growth has almost entirely excluded other species.

In the north-west of South Australia, in the myall-bluebush country, overgrazing and destruction of the bluebush results in its replacement, under certain conditions, by *K. pyramidata* (black bluebush), which is a free seeding, unpalatable species. The black bluebush plays a very important part in the degeneration of the pasture since it still affords excellent protection to the soil. Unfortunately, however, the species does not grow to any extent on the shallower soils with their accumulation of lime near the surface, such as are found in the north-east where *K. pyramidata* is practically restricted to watercourses. Here the soil contains little lime. Restriction of *K. pyramidata* to watercourses in the north-east does not appear to be due to soil moisture relationships, since the species does grow on higher ground where the lime at at greater depth and also on stony hills with a thin cover of soil and no moisture-holding subsoil. Further, *K. pyramidata* is absent on highly calcareous soils in areas receiving comparatively good rainfall for bluebush country.

As a result of the absence of a *K. pyramidata* stage in the degeneration of the *K. sedifolia* dominant pastures of the north-east, the destruction of the bluebush presents a much more serious problem than in the north-west of the State.

A study of the arid flora indicates the following points with regard to land administration:

(1) The fallacy of any fixed carrying capacity. This should be a fluctuating value assessed each year, and will depend largely upon seasonal conditions.

(2) The importance of rigid control of stock numbers during times of drought when herbaceous plants are absent and the perennial bush is under climatic stress. Loss of bush invariably occurs during droughts because of the excessive grazing it receives.

(3) Increase of sheep numbers in good years above the carrying capacity of the average seasons should be permitted. When there is an abundance of herbage and grass, sheep do not harm the less palatable bush cover.

(4) The fallacy of spelling paddocks which have lost completely their saltbush or bluebush. Unless seed is re-introduced when there is a cover of bindyi, etc., on the land, a permanent cover can never be re-attained. A temporary cover of herbaceous species may result, only to dry off and be blown away. Such herbage might just as well be utilized.

(5) The bluebush (*K. sedifolia*) country of the north-east of the State requires careful examination from time to time to determine whether the bush is being overgrazed. It is important that here a sub-stage of black bluebush is lacking when deterioration in the plant cover occurs. As a result the dangers of soil instability following overgrazing are much more serious than on the sandy brown solonized soils of the north-west of South Australia, where killing of bluebush often results in its replacement by black bluebush.

(6) The importance of spelling paddocks that still contain bush before all seed plants are destroyed. When the bush cover is obviously becoming thin, stock should be removed (in good years) to enable seeding and seedling establishment to take place.

(7) A balance between herbaceous plants and perennial shrubs should be aimed at. Moderate grazing is beneficial, in that it causes pruning of the bush. Some thinning of the original bush cover is on some country desirable to promote the growth of herbage. Through competition for moisture, closed

communities of bush prohibit the growth of herbaceous plants (and also the establishment of bush seedlings).

(8) Carrying capacity should not be determined solely on area of country but also on the numbers of waters, and particularly an assessment of the condition of the pastures, quantity and types of fodder plants. Increased number and correct spacing of waters in many cases would enable the more uniform grazing of the country and lower the concentration of stock about existing waters. Large numbers of sheep in a large paddock, with only one water, results in severe overgrazing and trampling of bush and its ultimate removal around the water, and progressive zones of less intensively grazed bush for a radius of 3 or 4 miles, the normal grazing range of sheep in this country. It is only during the winter when the sheep do not water or following heavy rains in the summer when swamps, claypans, etc., are full, that the portions of large paddocks furthest from water are grazed.

(9) Those responsible for land administration of pastoral country should be able to recognise at an early stage indications of degeneration of the plant cover. If we are going to stock the country for long-term economic returns we must of necessity sacrifice some of the most palatable plants, but at a certain level which can only be ascertained by a study of the plant communities, an equilibrium between stock and plants should be maintained. In the bluebush country of the north-east the best single indicator of condition of the plant cover is the bindyi, *Bassia patenticuspis.* A high frequency of occurrence of this species indicates excessive stocking.

The Distribution of the Species

A plant association is made up of species whose climatic and edaphic ranges, at least in part, coincide with those of the dominant. The dominants are frequently more specific than the associated species in their requirements, particularly the moisture status of the soil, so that the associated species often have a wider distribution. When the environmental conditions required by the dominant are most like those of any associated species, the species reaches its maximum development and has a high frequency of occurrence in the association which takes its name from that dominant.

In the area considered in this paper the sifting effect of declining rainfall on the botanical composition of the plant assemblage is ideally studied. As the species approaches the limits of its rainfall range on the drier side it gradually becomes less common and eventually drops out altogether. It may, however, occur under more arid conditions in restricted favourable habitats such as watercourses, swamps, etc. The result is a localized collection of plants typical of higher rainfall country.

Some species have a very wide distribution beyond the lower limit of their rainfall requirements in these specialized habitats, while others disappear rapidly. Not all the plants growing in watercourses and swamps are outside of their normal rainfall range. Species like *Trigonella suavissima* and *Erodiophyllum elderi* only grow in swamps and watercourses. The upper limit of rainfall of the species appears to be determined by competition rather than the appearance of any other limiting factor. Other more vigorous plants which are better fitted to the environment take its place.

In Table VIII which sets out the distribution of all the species which grow in the area, an attempt has been made to define some of the total rainfall requirements of the plants. This is a first approximation only, since the physical texture of the soil, slope and evaporation have a large measure of control over the moisture

available. Thus on sandy soils a species may be found under conditions of lower rainfall than on heavier-textured soils. Similarly, a species which normally has a certain upper limit of rainfall may be found in somewhat higher rainfall country under certain conditions. However, the important point in both cases is that the moisture available to the plants in these "specialized" occurrences is at a similar level to that in their normal rainfall ranges. Thus the species may grow under conditions of higher rainfall than normal on steep slopes or shallow soils where there is some measure of edaphic aridity.

Plants growing in any area in equilibrium with their environment give an indication of the moisture status of the soil. For example, the occurrence of red gums along creeks in arid areas indicates that the moisture status in the root zone of the red gums must be at least equivalent to that in the red gum dominant country near Keyneton, where the rainfall is in excess of 23" per annum.

A knowledge of the rainfall requirements of the plant species will enable the construction of maps showing isohyets of soil moisture availability, and in areas where few rainfall recording stations exist but where the plants and their normal rainfall requirements are known a consideration of the environment will enable construction of more accurate maps showing rainfall isohyets.

The following notes were made on the distribution of the species.

Erodiophyllum elderi is not found south of Braemar, and in fact is very rare in the area. It is a species found in watercourses and flooded ground in portions of the north-east of South Australia.

Kochia planifolia does not occur south of Kia Ora.

Casuarina lepidophloia, near Whyalla, is a dominant species in an area receiving 10" rainfall per annum. Societies of black oak are found in somewhat higher rainfall country.

Dactyloctenium radulans does not occur south of Braemar and is rare in the area, since it is on the southern limits of its range.

Eremophila sturtii is restricted to the country north of Kia Ora and is rare in the area, since it is on the southern limits of its range.

Zygophyllum iodocarpum is found only in the extreme north of the *M. platycarpum – K. sedifolia* and black oak association habitats.

Chloris truncata and *Lavatera plebeja* are limited to watercourses in the *M. platycarpum – K. sedifolia* and black oak associations, being typical of higher rainfall country. They were, however, only recorded in these two associations in the area studied.

Trigonella suavissima is on the southern limits of its range in the area and is of rare occurrence. It grows only in watercourses and swamps.

Chenopodium nitrariaceum: Two forms are found—a large-leafed erect growing variety which occurs only in swamps, and a small-leafed dwarf undershrub which grows only on highly calcareous soils which carry *K. sedifolia*.

Babbagia acroptera does not occur south of the Eudunda-Morgan railway line.

Atriplex vesicarium does not occur naturally south of the Eudunda-Morgan railway line, but has been successfully established there artificially. It only grows in the *E. oleosa – E. brachycalyx* and *E. oleosa – gracilis* associations adjacent to *M. platycarpum – K. sedifolia* or black oak associations.

Myoporum deserti, in the area discussed, does not occur in country which receives more than 12" of rain per annum.

Exocarpus aphylla does not occur in the area where the rainfall exceeds 13" per annum, but occurs elsewhere under conditions of somewhat higher rainfall.

Acacia acinacea, in the three Counties, is restricted to a small area north-east of Terowie.

Callitris glauca occurs only in the northern portion of the area. It is found principally in the ranges north-east of Hallett and Terowie, and also in the ranges on Pualco.

Codonocarpus pyramidalis in this area is found only in the ranges north-east of Mount Bryan.

Eremophila oppositifolia does not occur south of the Morgan-Eudunda railway.

Solanum ellipticum is found only in the far north of the area studied, and apart from its occurrence in the hills carrying *Dodonaea–Eremophila - Acacia* association is restricted to watercourses.

Trichinium obovatum is found only in the far north of the area and is limited to skeletal soils.

Goodenia cycloptera occurs only in the north of the area. Where the rainfall is less than about 8″ per annum it is restricted to watercourses.

Bassia obliquicuspis is found only in the north of the area and is here on the southern limits of its range.

Kochia triptera, on sandy soils, grows in country receiving less than 8″ per annum in the north-west of the State.

Atriplex stipitatum is very rarely found where the rainfall is less than 8″ per annum.

Schismus barbatus is found only in watercourses and on sand accumulations where the rainfall is less than 8″ per annum. It is near the extreme lower limits of its range at about this rainfall.

Acacia colletoides does not grow where the rainfall is less than about 8″ per annum. It is found in the *M. platycarpum – K. sedifolia* association and the black oak country only adjacent to mallee.

Cryptandra amara var. *longiflora* occurs from Keyneton northwards through the ranges to the hills west of Collinsville.

Anguillaria dioica was not recorded below 12″ rainfall country in this area, but it occurs in the north-west of the State on sandy soils in areas receiving about 7″ per annum.

Exocarpus cupressiformis and *Daviesia ulicina* were not recorded in this area where the rainfall was below 21″ per annum, and *Thomasia petalocalyx* and *Astroloma humifusum* below 22″ per annum. Elsewhere these species occur under conditions of much lower rainfall.

ACKNOWLEDGMENT

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Table VIII

Showing the distributions of the plants growing in the area. x denotes the presence of the species in the association. The associations are as follows:—(1) *Eucalyptus camaldulensis*, (2) *Eucalyptus leucoxylon*, (3) *Casuarina stricta*, (4) *E. odorata*, (5) *Lomandra* spp., (6) *E. anceps*–*E. dumosa*, (7) *E. oleosa*–*E. brachycalyx*, (8) *E. oleosa*–*E. gracilis*, (9) *Eremophila*–*Dodonaea*–*Acacia*, (10) *Myoporum platycarpum*–*Kochia sedifolia*, (11) *Casuarina lepidophloia*.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	Limit of rainfall
Eutaxia microphylla	x											lower 23"
Astroloma humifusum	x											—
Pteridium aquilinum	x											,, 24"
Danthonia setacea	x											,, 23"
Cynosurus echinatus	x											,, 23"
Rumex pulcher	x											—
Poa australis	x											,, 22"
Drosera pygmaea	x											,, 22"
Lomandra fibrata	x											—
Asclepias rotundifolia	x											—
Iris germanica	x											,, 23"
Rumex acetosella	x											,, 23"
Daviesia ulicina	x	x										—
Acacia rhetinodes	x	x										,, 21"
Dillwynia floribunda	x	x										,, 22"
Thomasia petaloclayx	x	x										—
Trifolium subterraneum (Mt. Barker strain)	x	x										,, 21"
Briza minor	x	x										,, 20"
Velleia paradoxa	x	x										—
Bromus mollis	x	x										,, 21"
Geranium pilosum	x	x										,, 19"
Geranium molle	x	x										,, 22"
Drosera whittakeri	x	x										—
Trifolium glomeratum	x	x										,, 20"
Stipa drummondii	x	x										,, 19"
Rosa canina	x	x										,, 19"
Acaena ovina	x	x	x									,, 18"
Halorrhagis elata	x	x	x									,, 17"
Kennedya prostrata	x	x	x									,, 17"
Scirpus sp.	x	x		x								—
Aira caryophyllea	x	x	x	x								,, 17"
Briza maxima	x	x	x	x								,, 17"
Ranunculus lappaceus	x	x	x	x								—
Scleropoa rigida	x	x		x								—
Cheilanthes tenuifolia	x	x	x	x								,, 15"
Casuarina stricta	x	x	x	x	x							,, 14"
Pimelia glauca	x	x	x	x	x							,, 14"
Trifolium angustifolium	x	x	x	x	x							,, 16"
Hypochaeris radicata	x	x	x	x	x							,, 18"
Trifolium arvense	x	x	x	x	x							,, 15"
Themeda australis	x	x		x	x							,, 16"
Bromus madritensis	x	x			x							,, 17"
Chenopodium carinatum	x	x	x	x	x							—
Lolium subulatum	x	x	x	x	x							,, 13"
Moraea xerospatha	x	x	x	x	x							,, 15"

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	Limit of rainfall
Onopordon acanthium	x	x	x	x	x	.	.	.	.	.	.	,, 17"
Helichrysum apiculatum	x	x	x	x	x	x	.	.	.	.	.	—
Avena fatua	x	x	x	x	x	x	.	.	.	.	.	,, 12"
Anguillaria dioica	x	x	x	x	x	x	.	.	.	.	.	—
Cynodon dactylon	x	x	.	.	.	x	.	.	.	.	.	—
Oxalis cernua	x	x	x	x	x	x	x	.	.	.	.	,, 14"
Cryptostemma calendulaceum	x	x	x	x	x	x	x	.	.	.	.	,, 12"
Vulpia myuros	x	x	x	x	x	.	x	.	.	.	.	—
Lomandra dura	x	x	x	x	x	.	.	x	.	.	.	,, 13"
Acacia pycnantha	x	x	x	x	x	.	.	x	.	.	.	,, 12"
Bromus rigidus	x	x	x	x	x	.	.	x	x	.	.	,, 13"
Erodium botrys	x	x	x	x	x	x	x	.	x	.	.	,, 10"
Hordeum leporinum	x	x	x	x	x	x	x	.	x	.	.	,, 12"
Salvia verbenaca	x	x	x	x	x	x	x	.	x	.	.	,, 14"
Stipa eremophila	x	x	x	x	x	.	.	x	.	x	.	,, 13"
Romulea rosea	x	x	x	x	.	.	x	.	.	x	.	,, 11"
Eucalyptus camaldulensis	x	x	x	x	x	x	x	.	x	x	x	,, 23"
Stipa variabilis	x	x	x	x	x	x	x	x	x	.	.	—
Danthonia semiannularis	x	x	x	x	x	x	x	x	x	x	x	,, 8½"
Oxalis corniculata	x	x	x	x	x	x	.	x	x	x	x	,, 13"
Vittadinia triloba	x	x	x	x	x	x	x	x	x	x	x	,, 12"
Convolvulus erubescens	x	x	x	x	x	x	.	x	x	x	x	,, 10"
Enneapogon nigricans	x	x	x	x	x	x	x	x	x	x	x	—
Erechthites quadridentata	x	x	.	x	x	.	.	x	x	x	x	,, 14"
Wahlenbergia sp.	x	x	x	x	x	x	.	x	x	x	x	,, 12"
Echium plantagineum	x	x	x	x	x	x	x	x	x	x	x	,, 12"
Sonchus oleraceus	x	x	x	x	x	.	.	x	x	x	x	,, 14"
Solanum nigrum	x	x	x	x	x	x	.	.	x	.	x	,, 14"
Erodium cicutarium	x	x	x	x	x	.	.	x	x	x	x	—
Inula graveolens	x	x	.	x	x	x	x	.	x	x	x	,, 13"
Exocarpus cupressiformis	.	x	.	.	.	.	.	.	.	.	.	—
Lolium cylindricus	.	x	.	.	.	.	.	.	.	.	.	—
Calocephalus citreus	.	x	.	.	.	.	.	.	.	.	.	—
Eucalyptus leucoxylon var pauperita	.	x	.	.	.	.	.	.	.	.	.	—
Ulex europaeus	.	x	.	.	.	.	.	.	.	.	.	,, 19"
Plantago lanceolata	.	x	.	x	.	.	.	.	.	.	.	—
Clematis microphylla	.	x	.	x	.	.	.	.	.	.	.	—
Senecia lautus	.	x	.	x	.	.	.	.	.	.	.	—
Bulbine bulbosa	.	x	x	x	.	.	.	.	.	.	.	—
Acacia armata	.	x	x	x	x	.	.	.	.	.	.	,, 14"
Cryptandra amara var	.	x	.	x	x	.	.	.	.	.	.	14–23"
Trifolium tomentosum	.	x	.	x	x	.	.	.	.	.	.	lower 13"
Helipterum jessenii	.	x	x	x	x	.	.	.	.	.	.	13–22"
Dichopogon strictus	.	x	x	x	x	.	.	.	.	.	.	lower 16"
Cynara cardunculus	.	x	.	.	x	.	.	.	.	.	.	—
Foeniculum vulgare	.	x	x	x	.	x	.	.	.	.	.	—
Acacia brachybotrya	.	x	x	x	.	x	x	.	.	.	.	11–21"
Bursaria spinosa	.	x	x	x	x	x	x	x	.	.	.	lower 11"
Helichrysum retusum	.	x	.	x	.	.	.	x	.	.	.	—
Triodia irritans	.	x	.	.	x	.	.	x	.	.	.	—
Lomandra multiflora	.	x	x	x	x	x	.	x	.	.	.	lower 10½"
Aristida behriana	.	x	.	x	x	.	.	x	.	.	.	,, 11"
Eucalyptus leucoxylon	.	x	.	.	x	.	.	.	.	.	.	,, 18"
Sherardia arvensis	.	x	.	.	x	.	.	.	x	.	.	,, 14"

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	Limit of rainfall
Callitris propinqua	.	x	.	x	x	x	x	.	x	.	.	9–19″
Medicago trunculata	.	x	x	x	x	x	x	x	x	.	.	lower 13″
Dianella revoluta	.	x	.	x	x	x	x	.	x	.	.	„ 9″
Rhagodia nutans	.	x	x	x	x	x	x	x	x	x	.	„ 11″
Trichinium spathulatum	.	x	x	x	x	x	x	x	x	x	.	—
Polygonum aviculare	.	x	.	.	.	.	.	.	x	x	.	—
Asphodelus fistulosus	.	x	x	.	x	.	.	.	x	x	.	„ 12″
Onopordon acaule	.	x	x	x	x	x	x	.	x	x	.	„ 12″
Carthamus lanatus	.	x	x	x	x	x	x	x	x	x	.	„ 12″
Dodonaea attenuata	.	.	x	x	.	x	x	x	x	.	x	—
Enchylaena tomentosa	.	x	x	x	x	x	x	x	x	x	x	upper 21″
Kochia brevifolia	.	x	x	x	x	x	x	x	x	x	x	8–20″
Medicago minima	.	x	x	x	x	x	x	x	x	x	x	lower 12″
Euphorbia drummondii	.	x	.	x	x	x	x	x	x	x	x	upper 21″
Medicago hispida	.	x	x	x	x	x	x	x	x	x	x	lower 13″
Lepidium hyssopifolium	.	x	.	x	x	x	x	.	x	x	x	„ 9″
Schismus barbatus	.	x	.	x	x	x	x	x	x	x	x	upper 17″
Salsola kali	.	x	x	x	x	x	x	x	x	x	x	„ 22″
Stipa elegantissima	.	x	x	x	x	x	x	x	x	x	x	lower 8″
Marrubium vulgare	.	x	x	x	x	x	x	.	x	x	x	„ 11″
Heliotropium europaeum	.	x	.	x	x	x	x	x	x	x	x	upper 23″
Sida corrugata	.	x	.	x	x	x	x	x	x	x	x	„ 20″
Scabiosa maritima	.	.	x	.	.	.	.	.	.	.	.	—
Rhagodia parabolica	.	.	x	x	.	x	x	x	.	.	.	11–17″
Atriplex semibaccatum	.	.	x	.	x	x	x	.	x	.	.	9–18″
Nicotiana glauca	.	.	x	x	x	.	x	x	x	x	x	—
Callistemon teretifolius	.	.	.	x	.	.	.	.	.	.	.	—
Eucalyptus calcicultrix	.	.	.	x	.	.	.	.	.	.	.	—
Trichinium alopecuroideum	.	.	.	x	.	.	.	.	.	.	.	—
Acacia spinescens	.	.	.	x	x	.	.	.	.	.	.	lower 14″
Lotus australis	.	.	.	x	x	.	.	.	.	.	.	—
Cassytha melantha	.	.	.	x	.	x	x	.	.	.	.	—
Lycium ferocissimum	.	.	.	x	x	x	x	.	x	.	.	„ 10″
Rhagodia crassifolia	.	.	.	x	.	x	x	.	x	.	.	10–18″
Eucalyptus odorata	.	.	.	x	x	x	x	x	x	x	x	14–21″
Atriplex muelleri	.	.	.	x	x	x	x	x	x	.	.	upper 17″
Myoporum platycarpum	.	.	.	x	.	x	x	.	x	x	x	„ 19″
Pittosporum phillyreoides	.	.	.	x	.	x	x	x	x	x	x	„ 16″
Kochia georgei	.	.	.	x	x	x	x	x	x	x	x	„ 14″
Zygophyllum fruticulosum	.	.	.	x	.	x	x	.	x	.	x	„ 17″
Bassia uniflora	.	.	.	x	x	x	x	x	x	x	x	„ 18″
Cassia sturtii	.	.	.	x	x	x	x	x	x	x	x	upper 19″
Kochia aphylla	.	.	.	x	x	x	x	.	x	x	x	11–19″
Hakea leucoptera	.	.	.	x	x	.	x	x	x	x	x	upper 15″
Acacia colletoides	.	.	.	x	x	x	x	.	x	x	x	8–17″
Cassia eremophila var. platypoda	.	.	.	x	x	x	x	x	x	x	x	upper 14″
Rhagodia gaudichaudiana	.	.	.	x	.	x	x	x	x	x	x	„ 15″
Erodium cygnorum	.	.	.	x	x	x	x	x	x	x	x	„ 16″
Muehlenbeckia cunninghamii	.	.	.	x	x	x	.	.	x	x	x	—
Lepidosperma sp.	.	.	.	.	x	.	.	.	.	.	.	—
Xanthorrhoea quadrangulata	.	.	.	.	x	.	.	.	.	.	.	—
Kochia tomentosa var. humilis	.	.	.	.	x	.	.	.	.	.	.	—
Salvia aethiopis	.	.	.	.	x	.	.	.	.	.	.	—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	Limit of rainfall
Acacia ligulata	.	.	.	.	x	x	.	.	x	.	.	—
Sisymbrium orientale	.	.	.	.	x	x	x	.	x	.	.	—
Eucalyptus largiflorens	.	.	.	.	x	.	x	.	x	.	.	—
Cymbopogon exaltatus	.	.	.	.	x	.	.	.	x	x	.	—
Acacia oswaldii	.	.	.	.	x	x	x	.	x	x	x	„ 14"
Lycium australe	.	.	.	.	x	.	.	.	x	x	x	—
Eremophila longifolia	.	.	.	.	x	x	x	x	x	x	x	„ 14"
Rhagodia spinescens	.	.	.	.	x	x	x	x	x	x	x	„ 14"
Acacia victoriae	.	.	.	.	x	.	.	.	x	.	x	—
Nitraria schoberi	.	.	.	.	x	.	x	.	x	x	x	—
Teucrium racemosum	.	.	.	.	x	x	x	.	x	x	x	10–15"
Blennodia trisecta	.	.	.	.	x	.	.	.	x	x	x	8–13"
Bassia sclerolaenoides	.	.	.	.	x	x	.	.	x	x	x	upper 13"
Zygophyllum ammophilum	.	.	.	.	x	.	x	.	x	x	x	—
Xanthium spinosum	.	.	.	.	x	.	.	.	x	x	x	—
Citrullus vulgaris	.	.	.	.	x	x	x	.	x	x	x	—
Malva parviflora	.	.	.	.	x	.	.	.	x	x	x	—
Eucalyptus anceps	.	.	.	.	.	x	.	.	.	.	.	12–14½"
Olearia floribunda	.	.	.	.	.	x	.	.	.	.	.	—
Eucalyptus dumosa	.	.	.	.	.	x	.	.	.	.	.	—
Eremophila divaricata	.	.	.	.	.	x	x	.	.	.	.	—
Acacia notabilis	.	.	.	.	.	x	x	x	x	.	.	8–15"
Melaleuca pubescens	.	.	.	.	.	x	x	.	x	.	.	lower 9"
Westringia rigida	.	.	.	.	.	x	x	.	x	.	.	9–15"
Grevillea huegelii	.	.	.	.	.	x	x	.	x	.	.	8–15"
Atriplex rhagodiodes	.	.	.	.	.	x	x	.	x	.	.	upper 15"
Bassia parviflora	.	.	.	.	.	x	x	.	x	.	.	7–14"
Acacia calamifolia	.	.	.	.	.	x	x	x	x	.	.	9–15"
Eucarya sp.	.	.	.	.	.	x	x	x	x	x	x	—
Atriplex campanulatum	.	.	.	.	.	x	x	x	x	x	x	—
Heterodendron oleifolium	.	.	.	.	.	x	x	x	x	x	x	upper 13"
Cassia eremophila	.	.	.	.	.	x	x	x	x	x	x	„ 14"
Nicotiana sp.	.	.	.	.	.	x	.	x	x	x	x	lower 10"
Reseda luteola	.	.	.	.	.	x	x	.	x	.	x	—
Acacia microcarpa	.	.	.	.	.	.	x	.	.	.	.	—
Eucalyptus brachycalyx	.	.	.	.	.	.	x	.	.	.	.	10½–12"
Chenopodium desertorum	.	.	.	.	.	.	x	.	x	.	.	—
Chenopodium microphyllum	.	.	.	.	.	.	x	.	x	.	.	—
Kochia triptera	.	.	.	.	.	.	x	.	x	.	.	7–12"
Olearia muelleri	.	.	.	.	.	.	x	.	x	.	.	8–13"
Eucalyptus oleosa	.	.	.	.	.	.	x	x	x	.	.	8–16"
Eucalyptus gracilis	.	.	.	.	.	.	x	x	x	.	.	8–16"
Zygophyllum glaucescens	.	.	.	.	.	.	x	x	x	.	.	upper 13"
Mesembryanthemum crystallinum	.	.	.	.	.	.	x	.	x	.	.	—
Zygophyllum crenatum	.	.	.	.	.	.	x	x	x	x	.	upper 12"
Atriplex stipitatum	.	.	.	.	.	.	x	.	x	x	x	8–12"
Atriplex vesicarium	.	.	.	.	.	.	x	.	x	x	x	upper 12"
Kochia tomentosa	.	.	.	.	.	.	x	.	x	.	x	„ 12"
Atriplex vellutinellum	.	.	.	.	.	.	x	.	x	x	x	„ 12"
Myoporum deserti	.	.	.	.	.	.	x	x	x	x	x	—
Kochia sedifolia	.	.	.	.	.	.	x	.	x	x	x	„ 12"
Eremophila scoparia	.	.	.	.	.	.	x	.	x	x	x	„ 12"
Exocarpus aphylla	.	.	.	.	.	.	x	.	x	x	x	„ 13"

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	Limit of rainfall
Templetonia egena							x		x	x	x	,, 12"
Kochia tomentosa var. appressa							x	x	x	x	x	,, 15"
Kochia pyramidata							x	x	x	x	x	,, 13"
Tetragonia expansa							x	x	x	x	x	—
Atriplex spongiosum							x		x	x	x	,, 12"
Dodonaea lobulata								x				—
Acacia acinacea								x				—
Eremophila serrulata								x				—
Cassia artemesioides								x				—
Callitris glauca								x	x			,, 15"
Codonocarpus pyramidalis								x	x			—
Eremophila alternifolia								x	x	x	x	—
Eremophila oppositifolia								x	x		x	,, 10"
Solanum ellipticum								x	x	x	x	—
Trichinium obovatum								x	x	x	x	,, 13"
Sida petrophila								x		x	x	—
Chenopodium cristatum								x	x	x	x	,, 13"
Goodenia cycloptera								x	x	x	x	8–13"
Cratystylis conocephala									x			7–11"
Beyeria leschenaultii									x			—
Lepidium leptopetalum									x			—
Olearia pimelioides									x			—
Blennodia cardaminoides									x			—
Centaura solstitialis									x			—
Centaurea calcitrapa									x			—
Carrichtera annua									x			—
Bassia obliquicuspis									x	x	x	upper 11"
Sida intricata									x	x	x	—
Atriplex angulatum									x	x	x	,, 12"
Bassia paradoxa									x	x	x	,, 11"
Bassia brachyptera									x	x	x	,, 12"
Atriplex limbatum									x	x	x	—
Babbagia acroptera									x	x	x	,, 9"
Tragus australianus									x	x	x	—
Paspalidium gracile									x	x	x	—
Eragrostis dielsii									x	x	x	,, 11"
Lotus australis var. parviflorus									x	x	x	,, 11"
Chenopodium nitrariaceum (small leafed variety)									x	x	x	,, 10"
Chenopodium nitrariaceum (large leafed variety)									x	x	x	swamps
Craspedia pleiocephala										x		—
Lepidium fasciculatum										x		—
Eremophila maculata										x	x	—
Marsilea drummondii										x	x	swamps water-courses
Trigonella suavissima										x	x	
Lavatera plebeja										x	x	—
Chloris truncata										x	x	—
Zygophyllum iodocarpum										x	x	upper 10"
Euphorbia eremophila										x	x	—
Eremophila sturtii										x	x	,, 8"
Bassia tricuspis										x	x	—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	Limit of rainfall
Stenopetalum lineare	.	.	.	.	.	.	.	.	.	x	x	—
Tribulus terrestris	.	.	.	.	.	.	.	.	.	x	x	—
Dactyloctenium radulans	.	.	.	.	.	.	.	.	.	x	x	„ 8″
Casuarina lepidophloia	.	.	.	.	.	.	.	.	.	.	x	„ 10″
Kochia planifolia	.	.	.	.	.	.	.	.	.	.	x	„ 10″
Erodiophyllum elderi	.	.	.	.	.	.	.	.	.	.	x	water-courses
Kochia tomentosa var. tenuifolia	.	.	.	.	.	.	.	.	.	.	x	—
Trichinium alopecuroideum var. rubriflorum	.	.	.	.	.	.	.	.	.	.	x	—

EXPLANATION OF PLATES II—IV

PLATE II

Fig. 1 *E. camaldulensis* association, Keyneton. The original pasture was dominated by *Danthonia semiannularis* and *Stipa variabilis* but overgrazing has resulted in predominance of annuals like *Avena fatua, Hordeum leporinum, Bromus rigidus* and *Erodium botrys.*

Fig. 2 *E. leucoxylon* association, Keyneton. *Acacia pycnantha, Stipa variabilis* and annual grasses are the principal associated plants. *Danthonia semiannularis* is also present but excessive grazing has resulted in reduction in the amount of *Danthonia* and a *Stipa* dominant pasture.

Fig. 3 *E. odorata* association east of Keyneton. The principal grass is *Stipa variabilis.*

Fig. 4 Typical *Casuarina stricta* association west of Sedan near the eastern scarp of the ranges. The herbaceous species are principally *Stipa variabilis* and *Danthonia semiannularis.*

PLATE III

Fig. 1 *L. dura—L. multiflora* association south of Burra. The grasses are principally *Danthonia semiannularis* and *Stipa variabilis.*

Fig. 2 *E. oleosa—E. brachycalyx* association east of Burra. The associated shrubs are *Atriplex vesicarium* and *A. stipitatum.*

Fig. 3 *E. oleosa—E. gracilis* association near Sedan. The associated shrub is *Cratystylis conocephala.* The bush has been overgrazed and thinned out resulting in replacement by the less valuable *Bassia decurrens,* the plant growing between the remaining bushes.

Fig. 4 *Eremophila—Dodonaea—Acacia* association near Terowie. Note the rock outcrops and bare ground largely devoid of herbaceous species in foreground.

PLATE IV

Fig. 1 *M. platycarpum—K. sedifolia* association, east of Burra. The bluebush has been heavily grazed and the stand thinned to some extent. The grass is *Stipa nitida.*

Fig. 2 *Casuarina lepidophloia* scrub north-west of Morgan. Associated with the black oak is *K.sedifolia* which has been very heavily grazed. The grass is *Stipa nitida.*

Fig. 3 Growth of *Stipa nitida* (spear grass) on country which oringinally carried bluebush. Braemar Station.

Fig. 4 Overgrazed bluebush country. The land in the background has been contour ploughed to stop run-off of water. Photo taken following abnormally good seasons but the soil in the foreground has not respnded to the rains. Loss of surface soil by wind erosion has left a mantle of limestone pebbles on the surface of the soil. Plants in middle foreground are *Sida intricata.* Paratoo Station.


Fig. 1


Fig. 2


Fig. 3

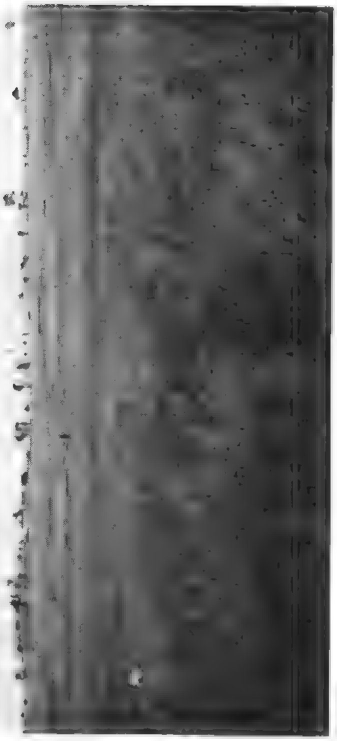
Fig. 4

Fig. 2

Fig. 4

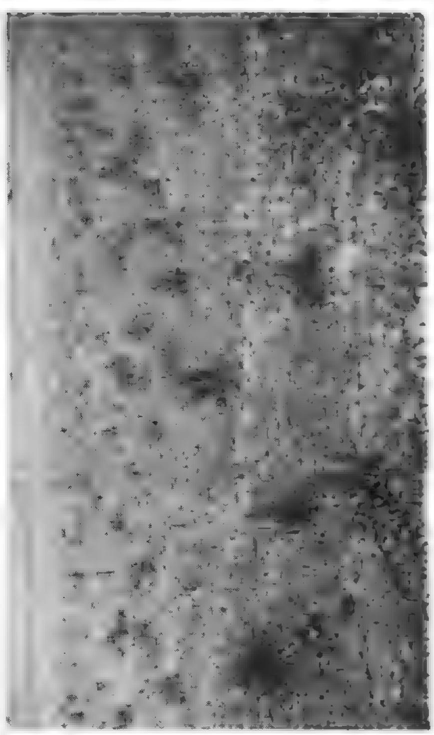

Fig. 1

Fig. 3

Fig. 2

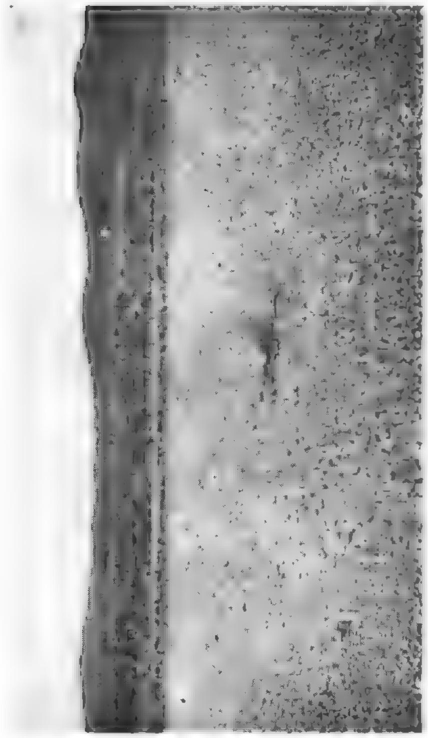

Fig. 4

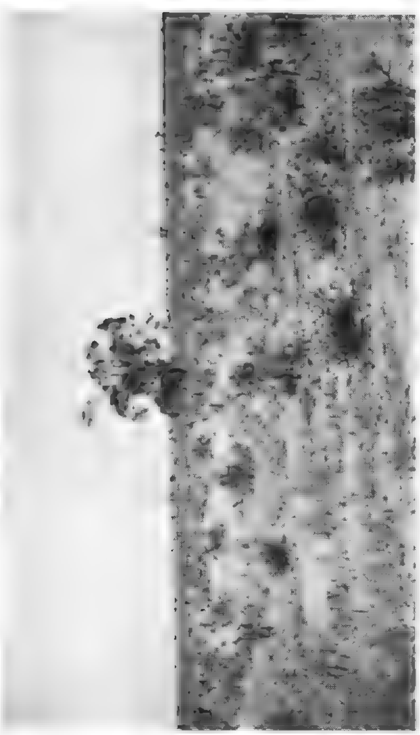

Fig. 1

Fig. 3

AUSTRALIAN ACANTHOCEPHALA

BY T. HARVEY JOHNSTON AND S. J. EDMONDS

Summary

The three species of echinorhynchs described in this paper were collected from birds. One (Centrorhynchus horridus Linst.) had been previously recorded from the Bismarck Archipelago; the second, Polymorphus biziurae, is described as new, and an account is given of its larval stage; the third, Gordiorhynchus hylae, is considered to be the adult stage of a larva described many years ago (Johnston 1912; 1914) from Eastern Australian frogs.

AUSTRALIAN ACANTHOCEPHALA
No. 7

By T. HARVEY JOHNSTON and S. J. EDMONDS *

[Read 13 May 1948]

(Fig. 1-20)

The three species of echinorhynchs described in this paper were collected from birds. One (*Centrorhynchus horridus* Linst.) had been previously recorded from the Bismarck Archipelago; the second, *Polymorphus biziurae*, is described as new, and an account is given of its larval stage; the third, *Gordiorhynchus hylae*, is considered to be the adult stage of a larva described many years ago (Johnston 1912; 1914) from Eastern Australian frogs.

Parasite	Host	Locality
Centrorhynchus horridus (Linst.)	*Halcyon sanctus*	Qld., N.S.W.
Polymorphus biziurae n. sp.	*Biziura lobata*	Sth. Aust.
larval stage	*Cherax destructor*	Sth. Aust.
Gordiorhynchus hylae (Jnstn.)	*Podargus strigoides*	Sth. Aust.
larval stage	*Limnodynastes dorsalis*	Sth. Aust.
" "	*Hyla aurea*	Sth Aust., N.S.W.
" "	*Hyla caerulea*	Qld.

We wish to acknowledge our indebtedness to Professor J. B. Cleland of Adelaide; Mr. J. T. Gray of Orroroo, S. Aust.; Messrs. G. G. and B. Jaensch of Tailem Bend; and Mr. L. Ellis of Murray Bridge, for assistance in obtaining material.

Type and typical specimens have been deposited in the South Australian Museum. No. 6 of this series of papers was published by us in the Records of the South Australian Museum, 8, (4), 1947, 555-562.

CENTRORHYNCHUS HORRIDUS (von Linstow, 1897)

Some material collected in 1919 by Dr. J. B. Cleland from the intestine of *Halcyon sanctus* at Stradbroke Island, Queensland, was examined by us and found to contain one male, four females and some fragments of this species. The specimens were not in a good state of preservation and have not cleared well. They are long and cylindrical and taper slightly towards the posterior extremity. The male is 9·3 mm. long and 0·8 mm. wide and the maximum dimensions of the females are, length 13·5 mm. and breadth 1·0 mm. The proboscis of the best preserved specimen is 0·55 mm. in length. It consists anteriorly of a cylindrical portion, 0·27 mm. long and 0·16 mm. wide, and posteriorly of a region 0·28 mm. long, the diameter of which gradually increases as it approaches the body of the worm. The maximum width of this posterior portion is 0·28 mm. We have not been able to determine the number of longitudinal rows of hooks. Each row, however, seems to consist of about 14 or 15 hooks. Their shape and arrangement resemble closely those of *C. horridus* given by Meyer (1932, fig. 102). The proboscis sheath is about 0·8 mm. long, is double-walled, and arises at about the level of the seventh or eighth hook. Two ellipsoidal testes of length 0·55-0·60 mm. and maximum width 0·35 mm. are situated in tandem in the anterior third of the male. The cement glands are long, cylindrical and pressed

* University of Adelaide.

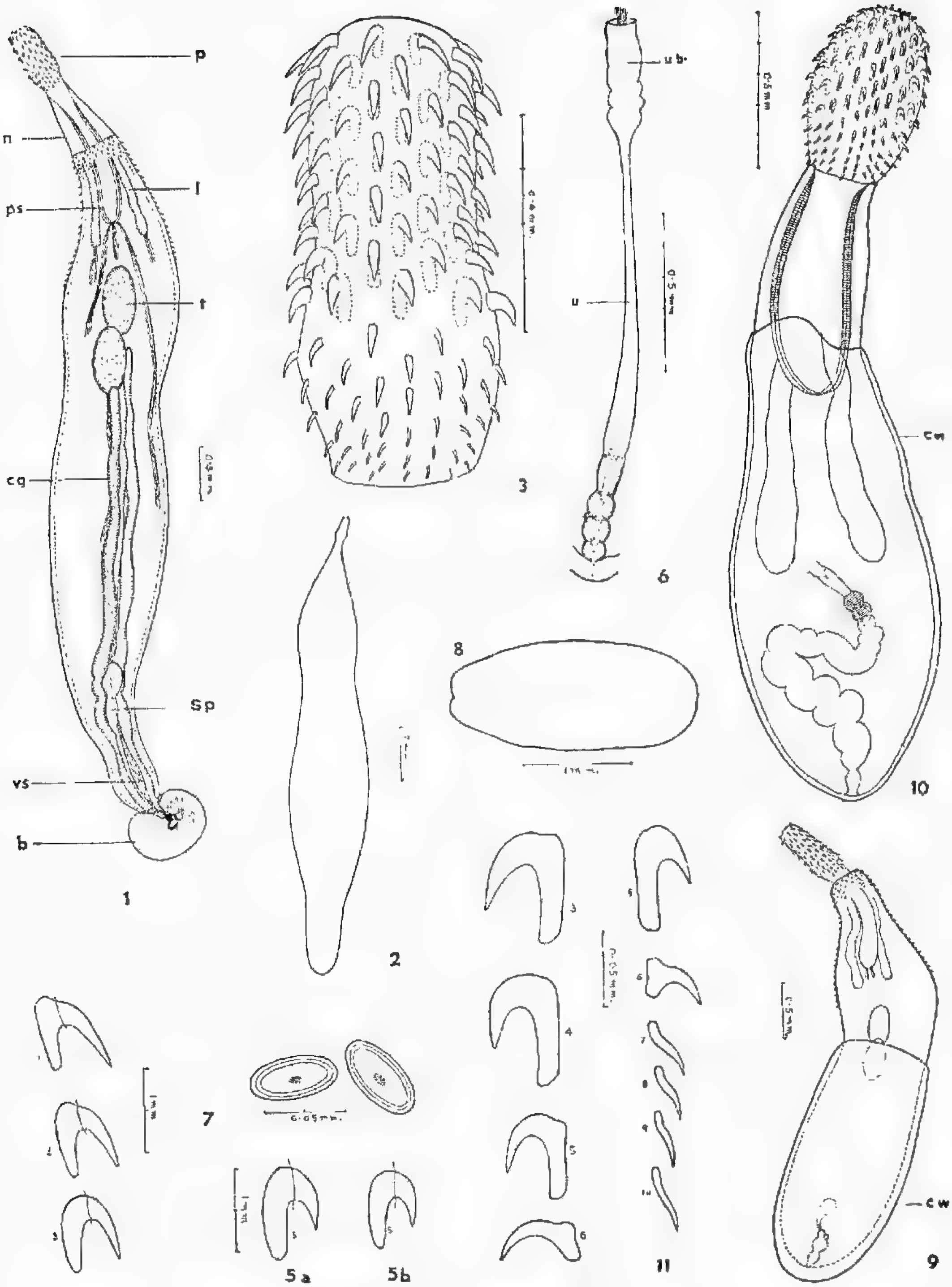

Fig. 1-9: *Polymorphus biziurae*

1, adult male; 2, adult female; 3, proboscis; 4, proboscis hooks 1-3 of each row, from large female; 5a hook 5, from large female; 5b hook 5 from small male; 6 female genitalia; 7 eggs; 8 cyst from *Cherax destructor*; 9, everted male larva.

Fig. 10-11 *Gordiorhynchus hylae*

10, everted female larva from *Limnodynastes dorsalis*; 11, some hooks from larvae. References to lettering—b, bursa; cg, cement gland; cw, cyst wall; fo, female aperture; gg, genital gland cell; la, lacunar vessel; l, lemniscus; n, neck; p, proboscis; ps, proboscis sheath; sph, sphincter; sp, Saefftigen's pouch; t, testes; u, uterus; ub, uterine bell; vd, vas deferens; vs, vesicula seminalis.

together. The male opening is terminal. Ovarial masses varying in diameter from 0·10 to 0·22 mm. are present in the females. The body cavity of two of the females contains eggs, which are 36-44 μ long and 14-18 μ wide. We have not been able to determine whether they are mature.

Our specimens agree closely in most details with the description of *C. horridus* as given by Marval (1905) and Meyer (1932, 119-20). In their census of Australian Acanthocephala, Johnston and Deland (1929, 149) reported that *Echinorhynchus* sp. probably *E. horridus*, had been collected from *Halcyon sanctus* in New South Wales by the senior author (Johnston 1910, 105). Travassos (1926, 58) transferred the species to *Prosthorhynchus*, and Meyer (1932, 119) to *Centrorhynchus*.

Polymorphus biziurae n. sp.

Fig. 1-9

About fifty specimens of this parasite in stages of development ranging from larvae with cyst wall still attached, to adults, have been collected on different occasions from musk ducks, *Biziura lobata*, obtained for us by G. G. and B. Jaensch, and L. Ellis at Tailem Bend on the River Murray. The males and the younger females are white, but the mature females are orange in colour. Both the males and females are constricted slightly in the anterior part of the body.

Adults

The length of the males is 6·2-9·0 mm. and that of the egg-bearing females 11·1-18·2 mm. The maximum width of the males is 0·8-1·4 mm. and that of the females 1·7-2·8 mm. The proboscis is cylindrical and in most cases it is slightly swollen in the posterior half. The proboscis of the specimens in our collection shows considerable variation in length, viz., 0·64-0·94 mm., that of the female in most cases being larger than that of the male. The maximum width of the proboscis is 0·26-0·35 mm. It is armed with 21-22 longitudinal rows, each of 9-11 hooks. The anterior five hooks of each row bear well-developed, posteriorly-directed rooting processes. The shape and size of some of these hooks in the case of a large female are shown in fig. 4 and 5a. Fig. 5a and 5b show the relative sizes of identically situated hooks from a large female and small male respectively. Between the proboscis and the body there is an unarmed neck which, when fully extended, is 0·6-0·9 mm. long. In most of the specimens the neck is wholly or partly retracted. The anterior part of the body immediately behind the neck in both sexes bears a large number of minute spines. The proboscis sheath is double-walled and arises in the anterior portion of the neck. Its length is 1·3-2·3 mm. There are two lemnisci which appear to be from one to one and half times as long as the proboscis sheath. The body wall is thick and contains numerous small nuclei. The lacunar system consists of two longitudinal collecting vessels from which smaller anastomosing vessels arise.

Two ellipsoidal testes of approximately equal size lie in the anterior half of the male. Their length is 0·60-0·87 mm., and their maximum breadth 0·28-0·35 mm. Four long tubular cement glands arise near the level of the posterior testis. The bursa bears two anteriorly directed diverticula and the male opening is terminal.

The structure of the female reproductive organ is shown in fig. 6. The uterine bell is 0·35-0·43 mm. long and the uterus proper 1·1-1·6 mm. long. The vaginal sphincter is double and a gland cell surrounding the female aperture is in some cases very conspicuous, so that the vaginal complex then appears to consist of three bulbs. The female opening is terminal. Ripe eggs mounted in balsam are 58-65 μ long and 29-34 μ wide and are without polar prolongations.

We regard this parasite as a new species of the genus *Polymorphus*. It resembles rather closely *P. cucullatus* Van Cleave and Starrett (1940, 349) and *P. mutabilis* (Rudolphi 1819). It differs from the former in the number of proboscis hooks and from the latter in the size and the shape of its egg.

Encysted Form, Juveniles and Intermediate Host

Our material from *B. lobata* contains a number of everted larvae of *P. biziurae* with cyst wall still attached to the parasite. Measurements made on one male and one female larva after mounting in balsam are given below. Fig. 9 shows an everted male.

We have on a number of occasions obtained specimens of the yabbie, *Cherax destructor*, and yabbie fragments from the stomach and intestine of *B. lobata*. From some of these yabbies and fragments we have dissected out *Polymorphus* cysts. Our records show that from yabbies in the stomach and intestine of *B. lobata* or from those collected in the swamps at Tailem Bend, we obtained in October 1938, two *Polymorphus* cysts; October 1939, two; December 1941, one; March 1942, one; and March 1948, one. Measurements made of these cysts mounted in balsam show them to be the same as those cyst walls attached to the everted larvae of *P. biziurae* in the intestine of *B. lobata*. This evidence indicates that the yabbie, *Cherax destructor*, is the intermediate host of *P. biziurae*, the adult form of which occurs in the musk duck, *Biziura lobata*.

An attempt to infect a yabbie with the eggs of *P. biziurae* carried out in the aquarium of the Zoology Department of the University of Adelaide gave negative results. Perhaps the eggs of the parasite after laying require a period for further development before becoming infective.

Confirmatory evidence, however, that *Cherax destructor* is the intermediate host of *P. biziurae* comes from the following facts. At Tailem Bend in April 1947, larvae of *P. biziurae* along with yabbies were obtained from the stomach of the cormorant, *Microcarbo melanoleucus*. Five larvae with everted proboscis were also obtained from the rectum of this bird. At the same locality in December 1947 one cyst of *P. biziurae* along with shrimp and yabbie fragments was found in the gizzard of the spoon-bill, *Platalea flavipes*, and three larvae with fully everted proboscis were found in the lower intestine of the bird. The cormorant and the spoon-bill seem to be unsuitable as final hosts for this parasite, since the juveniles found in the rectum of these birds had not undergone any development beyond that seen in the cysts from the yabbie, although the proboscis had become everted.

The following table gives the measurements (in millimetres) made on the larvae from different birds and on the cysts contained in the yabbie.

	Cyst in *Cherax destructor*	Everted larvae from intestine of *Biziura lobata*		Everted larvae from rectum of *Microcarbo melanoleucus*		Everted larvae from rectum of *Platalea flavipes*	
		male	female	male	female	male	female
Cyst membrane:							
length - - -	2·2 – 2·4mm.	2·4mm.	2·2mm.	2·2mm.	2·0mm.	2·1mm.	1·9mm.
breadth - -	0·96 – 1·1	0·90	0·89	0·94	0·96	0·92	0·88
Length of worm		4·4	4·9	4·4	3·6	4·2	4·8
Maximum breadth		0·8	0·7	1·0	1·1	0·7	0·9
Proboscis, length		0·65	0·80	0·67	0·75	0·69	0·81
Testes, length -		0·4		0·42		0·35	
Testes, breadth -		0·2		0·2		0·2	

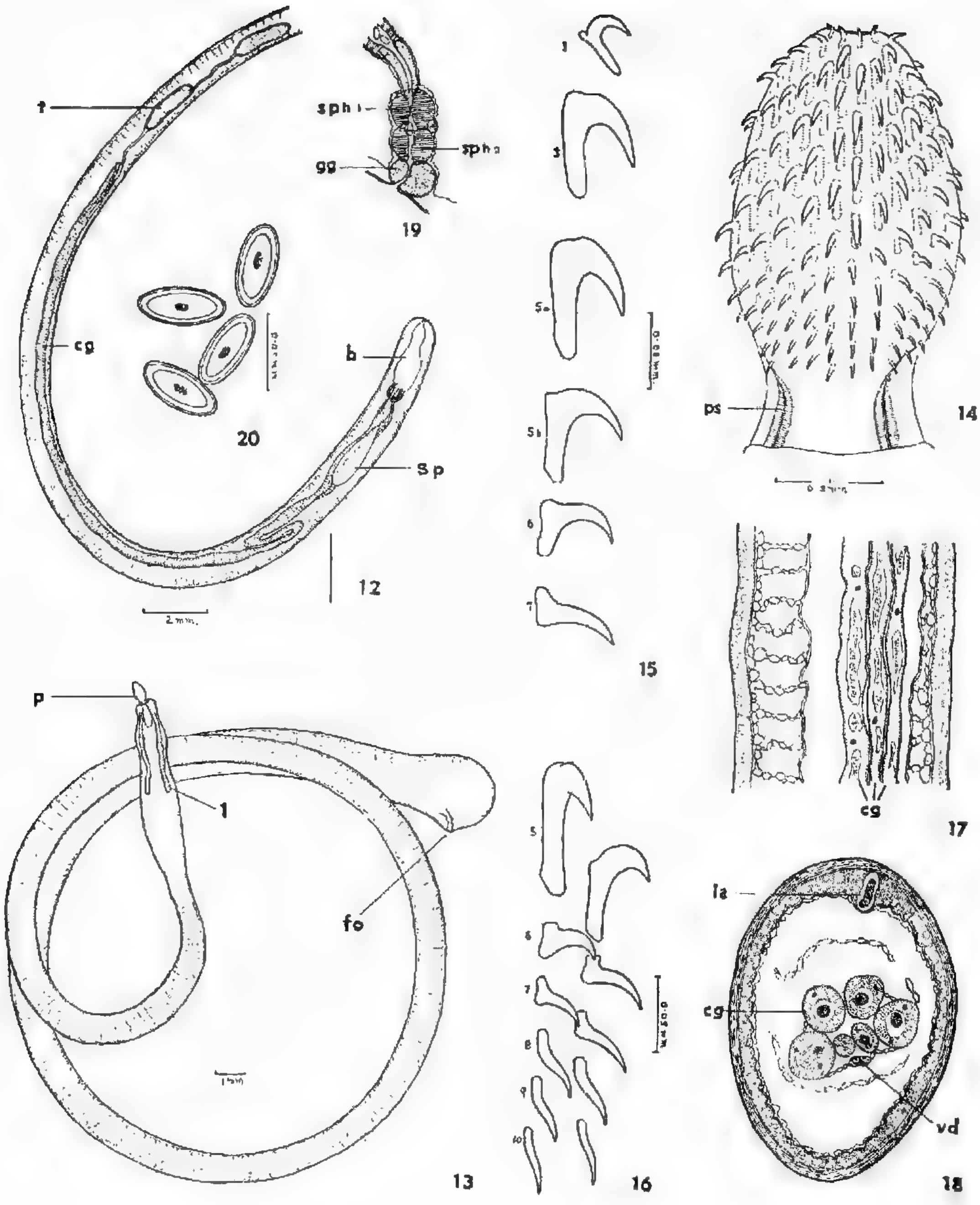

Fig. 12-20 *Gordiorhynchus hylae*
12, portion of male; 13, adult female; 14, proboscis; 15, some proboscis hooks from adult female; 16, proboscis hooks showing changes in form of the rooting processes; 17, L.S. male, showing inner pseudo-segmentation; 18, T.S. male showing six cement glands; 19, vaginal complex; 20, eggs.

The cysts from the crustacean may have one end slightly wider than the other and both extremities have a wide shallow depression, one of which contains the genital aperture. These larvae evert the proboscis if placed in fresh water. We have not found these larvae in any other animal living in the swamps.

GORDIORHYNCHUS HYLAE (Johnston) Johnston and Edmonds
Fig. 10-20

Four female and two male specimens of this echinorhynch were found in the intestine of *Podargus strigoides* at Orroroo, South Australia, in May 1939, by Mr. J. T. Gray. The worms are long, cylindrical and widest in the posterior region. Both sexes exhibit inner pseudo-segmentation of the type shown by *Gordiorhynchus clitorideus* Meyer (1930). The posterior extremity of the female is much swollen and rounded, and near the female genital opening there is a small epidermal protuberance. The body of both sexes is smooth.

The length of the males is 48-52 mm., and the maximum width 1·1-1·3 mm. The length of the females is 56-81 mm., and the maximum breadth 1·4-1·8 measured just in front of the rounded bulb at the posterior extremity of the worm. The diameter of this bulb is 1·9-2·5 mm. The proboscis is small in comparison with the length of the parasite. Its length is 0·55-0·65 mm., and its maximum breadth 0·37-0·43 mm. Its width at the anterior extremity is 0·12-0·13 mm. Between the proboscis and the body there is a short unarmed neck 0·10-0·15 mm. long and 0·30 mm. wide. In the largest female the total length of the proboscis and neck is 0·75 mm. The proboscis is armed with 26-28 longitudinal rows, each of ten hooks. The first five hooks of each row are largest and possess well-developed posteriorly-directed rooting processes. These rooting processes of hooks six and seven are much reduced and an anteriorly-directed process appears. In hooks eight, nine and ten the processes are anteriorly directed. Fig. 15 and 16 show the general arrangement and size of some of the proboscis hooks. Occasionally a slight variation in the shape and arrangement of the hooks in a row is observable, e.g., fig. 15, hook 5 a. The proboscis sheath is double-walled and is inserted at the level of the tenth hook. The point of insertion of the sheath, therefore, does not divide the armed portion of the proboscis into two parts as is the case with the genera *Centrorhynchus* Lühe 1922 and *Gordiorhynchus* Meyer 1931. The width of the outer wall of the sheath is about 20 μ, and its length 1·1-1·6 mm. In one male specimen the sheath is very much constricted near its middle. The lemnisci are about 3-4 mm. long. There is one long and well-developed lacunar vessel from which anastomosing vessels arise. The body wall is thick and consists of an outer epidermal layer surrounding layers of circular and longitudinal muscle tissue. No nuclei were noticed in it. Transverse and longitudinal sections show that in both sexes an inner pseudo-segmentation is present similar to that occurring in the female of *G. clitorideus*. The structure of the pseudo-segmentation of the male is shown in fig. 17.

Two long and ellipsoidal testes of approximately equal length lie in tandem in the anterior half of the worm. Their dimensions are length 1·2-2·2 mm., and maximum breadth 0·42-0·60 mm. There appear to be six tubular cement glands pressed closely together. Four of these arise near the posterior testes. The cement reservoirs are long. The bursa bears two anteriorly directed diverticula and the male opening is terminal.

All the females in our collection are densely packed with eggs and ovarial masses, and we have not been able to trace completely the female genitalia. The vaginal complex consists of three bulbs, and the genital opening, marked by a swelling of the epidermis, is sub-terminal. As is the case in *G. clitorideus* the

ovarial masses develop in the larger, presumably dorsal, segments. Ripe eggs are ellipsoidal and when mounted in balsam are 54-60 μ long and 24-28 μ wide. They are without polar prolongations. The nucleus in some of the eggs seems to be dumb-bell-shaped.

Systematic Position

The genus, *Gordiorhynchus,* as conceived by Meyer (1931, 120-22), consists of Centrorhynchinae with inner pseudo-segmentation in the female and with an appendix near the female aperture. The sub-family, Centrorhynchinae Meyer 1931, consists of these Polymorphidae in which the insertion of the proboscis sheath divides the proboscis into two parts. Both the male and female specimens in our material show inner pseudo-segmentation, and the females possess a structure near the genital opening which seems to correspond to the appendix of *G. clitorideus.* Internal pseudo-segmentation in male specimens of the genus, *Gordiorhynchus,* has already been recorded in the case of *G. falconis* Johnston and Best (1943, 229). The proboscis of the parasites in our collection, however, is not divided into two portions by the proboscis sheath. The double-walled sheath in each of our specimens arises at the level of, or just posterior to, the level of the tenth hook of each row. We consider that the conception of the genus, *Gordiorhynchus,* should be widened to include echinorhynchs with inner pseudo-segmentation in one or both sexes.

Encysted Form

From time to time during class dissections in Adelaide University white acanthocephalan cysts have been obtained from the mesentery of the frogs, *Limnodynastes dorsalis* and *Hyla aurea.* The presence of these cysts in *H. aurea* in New South Wales and *H. caerulea* in Brisbane has already been reported by the senior author (Johnston 1912, 84-85; 1914, 83-84), who described the species (1914) as *Echinorhynchus hylae.* Meyer (1932, 252) placed the species amongst Acanthocephala incertae sedis. We have found that in many cases the proboscis of the encysted parasite can be made to evert if the cyst is freed from the mesentery and placed in fresh water. Fig. 10 shows a female specimen in the everted condition. The size of the proboscis and the shape, size and arrangement of the proboscis hooks show that this parasite is the encysted form of the worm which we have obtained from *Podargus strigoides.* The shape and size of some of the proboscis hooks of the larvae are shown in fig. 11 and are drawn to the same scale as thost of the adult shown in fig. 15 and 16. The following measurements have been made on the cysts and the everted larvae. Length of cyst 1·38-1·70 mm., and maximum breadth 0·45-0·63 mm. Length of proboscis 0·58-0·63 mm., and maximum width 0·35-0·40 mm., and armed with 28 longitudinal rows each of ten hooks. Length of larvae 2·1-3·0 mm., and maximum width 0·45-0·65 mm.

It seems to us probable that the adult stage will be found in other nocturnal predatory birds, since *Podargus* is not a common bird in the localities from which infected frogs were obtained. Travassos (1926, 43) and Meyer (1932, 117) mentioned that the larva of *Centrorhynchus tumidulus* occurred in certain frogs and snakes.

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CESTODES FROM AUSTRALIAN BIRDS I. PELICANS

BY T. HARVEY JOHNSTON AND HELEN GOLDTHORP CLARK

Summary

Three new species of cestodes belonging to the genus Hymenolepis have been obtained from the only Australian species of pelican, Pelecanus conspicillatus Temm. Our present material was collected from eight birds, all from Tailem Bend, South Australia, Messrs. G. G., Fred., and Bryce Jaensch of that town, and Mr. L. Ellis, now of Murray Bridge, assisting us very generously. The material was obtained whilst we were engaged in other parasitological research work, carried out with the assistance of the Commonwealth Research Grant to the University of Adelaide. Types of the new species have been deposited in the South Australian Museum.

CESTODES FROM AUSTRALIAN BIRDS
I. PELICANS

By T. Harvey Johnston and Helen Goldthorp Clark *

[Read 13 May 1948]

Fig. 1-17

Three new species of cestodes belonging to the genus *Hymenolepis* have been obtained from the only Australian species of pelican, *Pelecanus conspicillatus* Temm. Our present material was collected from eight birds, all from Tailem Bend, South Australia, Messrs. G. G., Fred., and Bryce Jaensch of that town, and Mr. L. Ellis, now of Murray Bridge, assisting us very generously. The material was obtained whilst we were engaged in other parasitological research work, carried out with the assistance of the Commonwealth Research Grant to the University of Adelaide. Types of the new species have been deposited in the South Australian Museum.

Hymenolepis murrayensis n. sp.

(Fig. 1-8)

This cestode was found in four of the eight birds examined. Egg-bearing worms were 90-185 mm. long by 0·75-·83 mm. in maximum breadth. Segments are broader than long, but in those which are gravid, the relative difference in dimensions is less marked.

The small scolex is distinctly marked off from the neck and measures 0·17-·25 mm. in diameter. The rostellar sac is 0·08 mm. wide and extends back as far as the posterior margin of the suckers. The rostellum has 20-22 hooks of two sizes and differing in shape (fig. 2, 3), the larger being 0·02 and the smaller ·016 mm. in total length (*i.e.*, the distance between two parallel lines placed one at each end of the hook). The hemispherical or ellipsoid suckers measure 0·08-·1 by ·1-·12 mm.

The unilateral genital pores lie in the middle of the edge of the segment. Elliptical calcareous corpuscles are scattered through the cortex. The ventral excretory canal of the poral side has a diameter about ten times that of the dorsal vessels. The ventral canal of the aporal side is very much narrower than its fellow. The excretory ducts pass below the genital ducts.

The testes develop before the ovary. Very early segments exhibit the outlines of the three testes and the cirrus sac, and those with mature testes show an immature ovary and yolk gland, while in later segments with a well-developed ovary the testes either are degenerating or have disappeared. One testis lies on the poral side of the segment, the other two on the aporal, one gland being more anterior and lateral than the other (fig. 4). In segments in which the ovary is just developing, the organs are about 0·11 mm. in diameter. The internal and external seminal vesicles can be seen most clearly in segments with a mature ovary and disintegrating testes. The external vesicula is retort-shaped and lies between the cirrus sac and the testes. Between the two vesicles is a coiled portion of the vas deferens. The internal vesicle occupies most of the length of the cirrus sac, and narrows gradually to the ejaculatory duct. The long narrow cirrus sac, which has a well-developed muscular wall, extends obliquely across three-fourths of the width of the segment and slightly under the overhanging part of the preceding segment. It measures 0·36-·37 by ·08-·09 mm. in segments with

* University of Adelaide.

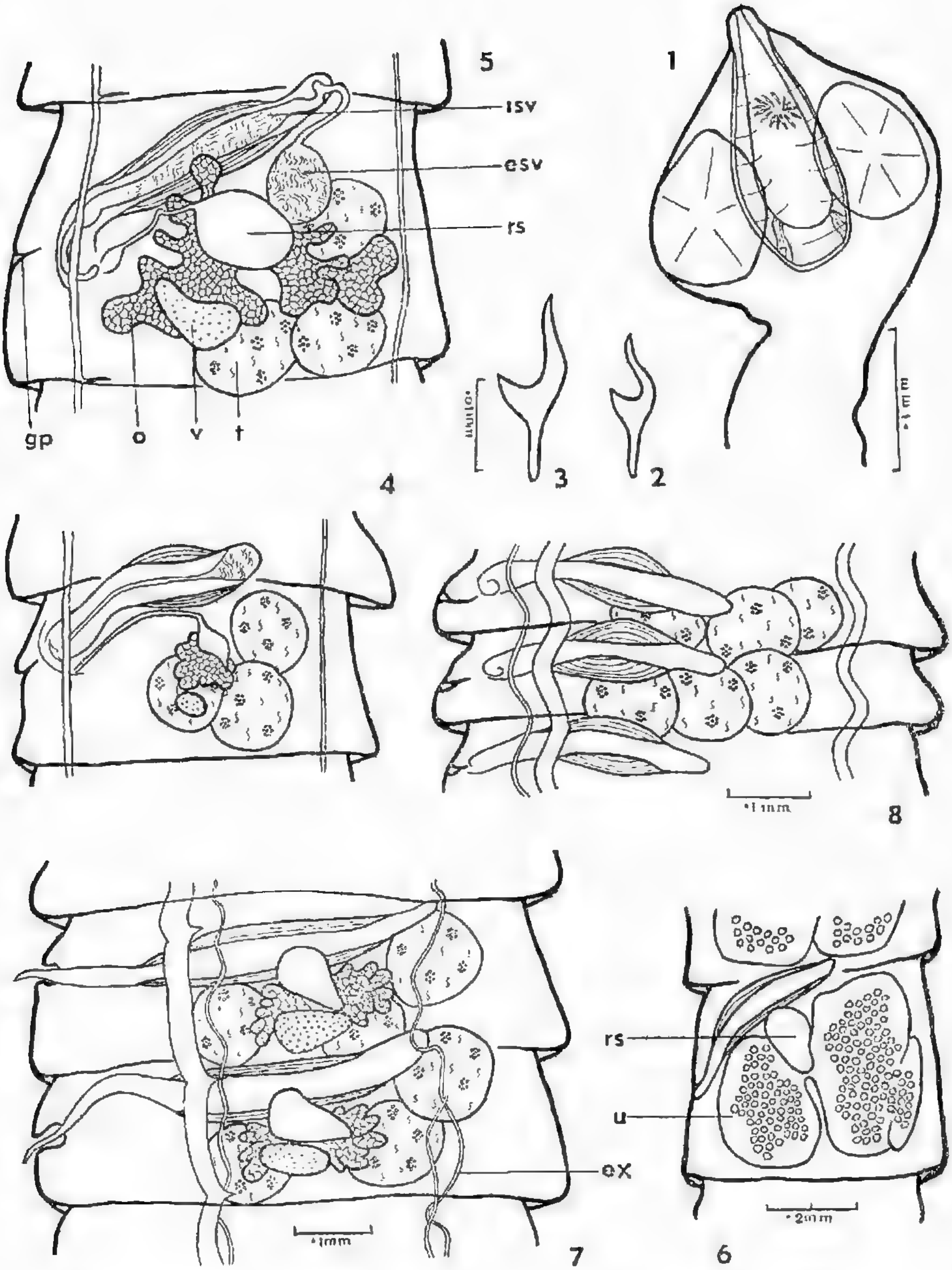

Fig. 1-8, *Hymenolepis murrayensis:* 1, scolex; 2, 3, rostellar hooks; 4, segment with mature testes; 5, segment with mature ovary; 6, gravid segment; 7, 8, segments from contracted strobilae. Fig. 2 and 3 to same scale; 4, 5, 8 to same scale. esv, external seminal vesicle; ex, excretory canal; gp, genital pore; isv, internal seminal vesicle; o, ovary; pr, prostate glands; rs, receptaculum seminis; t, testis; u, uterus; v, vitellarium.

mature testes, and 0·44-·52 by ·075-·08 mm. in those with a mature ovary. There is a chitinized ring around the opening of the sac into the genital atrium.

The ovary arises between the three testes and reaches its maximum size (0·25-·3 mm. in diameter) when the testes are degenerating (fig. 5). It has 15-20 well-marked lobes. The yolk gland is compact. The large chitinized seminal receptacle, 0·154 by ·113 mm., lies ventrally in front of the ovary, and, together with the cirrus sac, persists in gravid segments. The vagina travels behind the cirrus sac and parallel with it from the receptaculum to the genital atrium. The uterus arises as two lobes, one on either side of the ovary, but the organ later fills the segment and extends beyond the longitudinal excretory canals (fig. 6). Eggs measure about 0·04 by ·03 mm., the oncospheres 0·02 by ·014 mm., and the hooklets 8 μ long.

In this species the ratio of length to breadth of segments varies considerably according to the degree of contraction, and correlated with this the testicular arrangement shows variation. In strobilae with very short contracted segments the three testes lie almost in a straight line and the excretory canals are sinuous, but the number and sizes of the hooks agree with those of the more relaxed worms. Occasionally a strobila has some segments with a linear arrangement of the testes, whilst in others one aporal testes lies in front of the other. Some strobilae are more elongate, with segments squarish or even longer than broad.

The only other species of *Hymenolepis* with 20-22 hooks, described from Pelecaniform birds is *H. medici* Stossich, but the latter has hooks 0·03 mm. long, and its very large cirrus sac extends below the overlapping part of the preceding segment to its anterior aporal corner, and there is no aporal excretory canal (Fuhrmann, 1906, 749). *H. fictitia* Meggitt (1927 a) has 24 hooks, 34-39 μ and 48-52 μ in length. *H. magniuncinata* Meggitt (1927 b) has more than ten hooks measuring 39 μ, and *H. parvicirrosa* Meggitt (1927 b) has more than 14, measuring 43-48 μ, these two species being thus differentiated from *H. murrayensis* by the sizes of their hooks. In *H. phalacrocorax* Woodland (1929) originally described as unarmed, the testes lie outside the longitudinal excretory canals. According to Hughes' key to species of the genus (1941), *H. murrayensis* would be placed near *H. fictitia*.

Hymenolepis jaenschi n. sp.

(Fig. 9-13)

This species was found in the eight pelicans examined. Egg-bearing worms measure 40-85 mm. long and ·62-·67 mm. in maximum breadth, with segments broader than long.

The scolex (fig. 9), 0·3-·39 mm. in diameter is sharply marked off from the neck. The rostellar sac, 0·07 mm. wide, and 0·16-·24 mm. long, extends back to the posterior margin of the suckers. The everted rostellum is 0·22 by ·025 mm., and has 14 hooks in two alternating series, the larger hooks being 0·028 and the smaller 0·018 mm. long (fig. 10, 11). The suckers are about 0·2 mm. in diameter or 0·14 by ·18 mm. if elongate. The unilateral genital pores are at, or slightly in front of, the middle of the segment margin. The poral ventral longitudinal excretory canal is about 0·022-·026 mm. in diameter, while the aporal and the two dorsal canals are very narrow. Calcareous corpuscles are abundant.

The testes and ovary appear at about the same time in young segments, but the former tend to persist in segments in which the developing uterus has displaced the ovary. One testis is aporal, two lie in the extreme posterior region of the segment, the other aporal testis lying in front of the ovary. They measure 0·064-·08 mm. in diameter. The external seminal vesicle is rounded or oval.

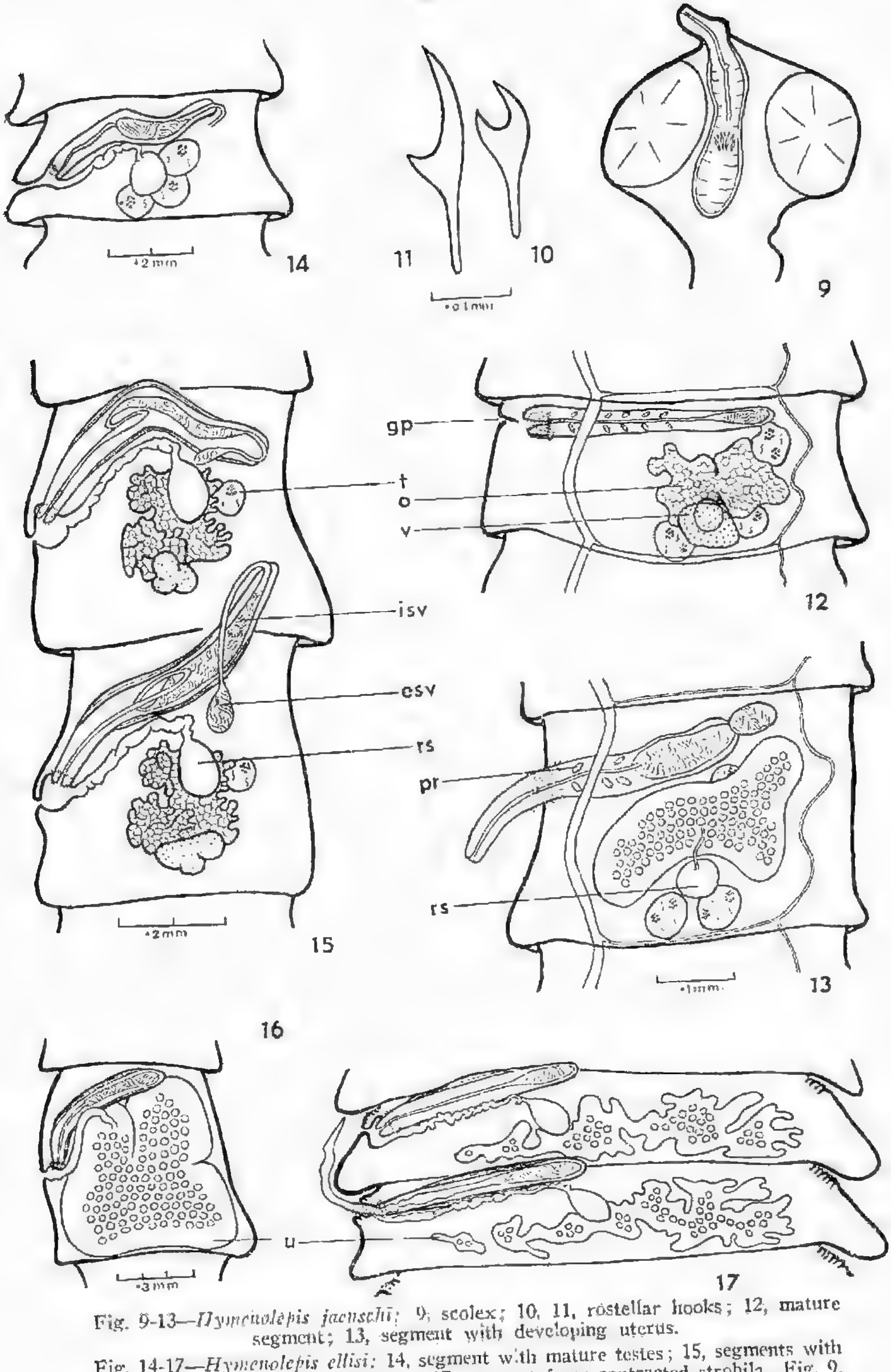

Fig. 9-13—*Hymenolepis jaenschi*; 9, scolex; 10, 11, rostellar hooks; 12, mature segment; 13, segment with developing uterus.

Fig. 14-17—*Hymenolepis ellisi*; 14, segment with mature testes; 15, segments with mature ovaries; 16, gravid segment; 17, segment from contracted strobila. Fig. 9, 12, 13 to same scale; fig. 10, 11; fig. 14 and 17.

0·058-·078 by ·05 mm.; the internal vesicle is elongate and may reach 0·05-0·116 mm. The thin-walled cirrus sac lies near the anterior margin of the segment and parallel with it; it measures 0·26-·29 by 0·05-·06 mm., and extends almost to the aporal excretory canal. There is a well-defined ring of small spines around the opening of the cirrus sac into the atrium, and the adjacent base of the cirrus is also provided with small spines for a distance of 0·05-·10 mm.

The ovary lies in the midregion of the segment between the testes and slightly toward the aporal side. Its two main lobes are subdivided into a total of about 8-10 lobules. It measures 0·052-·11. The large chitinized receptaculum lies behind the ovary, near the two posterior testes and dorsally to the yolk gland: it measures up to 0·073 by ·053 mm. in segments containing testes and uterus. The vagina travels forwards from the receptaculum and then parallel with the cirrus sac to the atrium. In gravid segments, the bilobed sac-like uterus fills the medulla and extends beyond the excretory ducts. It is about 0·4 mm. long and 0·5 mm. broad. Eggs measure 0·04 by 0·3 mm., and the oncospheres 0·02 by 0·15 mm., with hooklets 8 μ long.

We do not know of any species of *Hymenolepis* with 14 hooks described from Pelecaniform birds. *H. magniuncinata* Meggitt (1927 b) and *H. parvicirrosa* Meggitt (1927 b) have already been mentioned above, but their hooks differ in number and size from those of *H. jaenschi*. If grouped according to Hughes' key (1941), *H. jaenschi* would approach *H. fictitia* Meggitt, a species with 24 hooks, 0·034-·039 and 0·04-·052 mm. long.

Hymenolepis ellisi n.sp.

(Fig. 14-17)

The material consists of three fragments without scolices, collected in August 1942. They include mature and gravid segments and measure 60, 70 and 100 mm. in length, with breadths of 0·72, 1·04 and ·065 mm. respectively. Most segments are broader than long, but those which are gravid tend to be squarish or even longer than broad. The genital aperture is at about the middle of the margin.

The three round or elliptical testes (·065-·08 mm.) develop before the ovary. One is poral, the other two aporal, one of the latter being anterior to, and nearer the aporal edge of the segment than, the other. The external seminal vesicle lies aporally behind the end of the cirrus sac and measures 0·1-0·2 by ·08-·09 mm., or exceptionally 0·2 by 0·12 mm. The vas then continues as a narrow tube into the cirrus sac where it widens into a long internal seminal vesicle, 0·03-·04 mm. wide and varying in length according to its contents. The long ejaculatory duct is coiled when the cirrus is retracted. The cirrus sac is large and thin-walled and may curve to form an arc with its concavity directed posteriorly, or it may appear to project into the preceding segment. The organ measures 0·42-·48 by ·075-·085 in segments with mature testes, and may reach 0·5-·7 by ·07-·11 mm. in gravid segments. Surrounding its opening into the large deep atrium is a ring of small spines, and the series is continued on the base of the cirrus. These spines become detached readily.

The greatly lobed ovary lies in the middle of the section. It arises between the three testes, but the latter disappear by the time the ovary reaches its maximum size (0·25 mm. in width). The slightly lobed yolk gland measures 0·1-·13 by ·07-·09 mm. The thick-walled receptaculum lies between the ovary and cirrus sac, and measures 0·09-·11 by ·145-·16 mm. The wide vagina (average breadth ·035, maximum ·044 mm.) lies behind and parallel with the cirrus sac, and becomes slightly coiled as it passes ventrally to enter the receptaculum. The

uterus arises as two lobes, one on either side of the ovary, but when fully developed it forms a sac filling the medulla and extending beyond the excretory canals. Eggs measure about 0·04 by ·03 mm., the oncospheres 0·02 by ·015 mm., and the hooklets 7 μ in length.

Gravid fragments collected on another occasion probably belong to this species because of the resemblance of the external seminal vesicle, receptaculum, wide vagina, deep atrium, spined cirrus, and ring of spines around the opening of the cirrus sac into the atrium. The maximum width of these segments was 0·09-1·3 mm., and the cirrus sac measured 0·6-·75 by 0·8 mm.

This species differs from *H. murrayensis* in its spiny cirrus, thin-walled cirrus sac and the ring of spines around the outer aperture of the latter. It differs from *H. jaenschi* in its much larger cirrus sac, the position of the receptaculum, the disappearance of the testes before the ovary reaches its maximum size. The lack of a scolex prevents further comparison. The very large cirrus sac distinguishes it from all other *Hymenolepis* spp., from Pelecaniformes except *H. medici* Stossich. In his account of the latter, Fuhrmann (1906) did not give the measurement of the sac, but stated that it was very large, extending to the aporal anterior corner of the preceding segment or else bending into an arc in its own segment. The internal anatomy of the two species is rather similar. The finding of a scolex of *H. ellisi* should permit a decision as to the identity or otherwise of the two species.

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THE GENUS TRAGARDHULA BERLESE 1912 (ACARINA, TROMBICULIDAE)

By H. Womersley

Summary

In 1904 Tragardh (Results Swedish Zool. Exped. To Egypt and the White Nile 1901) described Trombidium niloticum from both larvae and adults found in apparent association and in large numbers on the leaves of an aquatic plant (Pistia stratiotes) on the White Nile (coll. Gebel Ahmed Aga 20 March 1901).

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By H. Womersley*

[Read 10 June 1948]

Fig. 1 A-G, fig. 2 A-J

In 1904 Trägårdh (Results Swedish Zool. Exped. to Egypt and the White Nile 1901) described *Trombidium niloticum* from both larvae and adults found in apparent association and in large numbers on the leaves of an aquatic plant (*Pistia stratiotes*) on the White Nile (coll. Gebel Ahmed Aga 20 March 1901).

For these larvae Oudemans 1911 (Entom. Ber., 3, (57), 123) erected the genus *Blankaartia* and later, in his monographic study of the larvae of the "Trombidiidae and Erythraeidae" (Zool. Jahrb., Suppl. 14, 1912), he figured and described the larvae in great detail. Trägårdh's adult material was studied by Berlese, who, in his monograph on the adult "Trombidiidae" (Redia 8, (1), p. 4, 1912) used the name *Tragardhula* as a subgenus of *Trombicula*. Later, however, in the same work (p. 96) he adopted Oudemans' name *Blankaartia* also as a subgenus of *Trombicula*.

The adult genus *Trombicula* as understood at the present time is characterised by the body being constricted medially, giving it a figure of 8 shape; by the elongate *crista metopica* with a subposterior sensillary area furnished with paired filamentous sensillae; eyes present or absent, but when present only one on each side of the crista and closely adjacent to, or away from, the sensillary area. In *Tragardhula nilotica*, however, they are placed well away from the crista and well in front of the sensillary area, as figured by Berlese (1912) and as seen in a specimen kindly given to me by the British Museum, which specimen was from *Pistia*, in India.

In the other known adult *Trombicula* species, either with eyes placed close to the sensillary area, or wanting, there are also other smaller features which enable them to be associated with some at least of the many larval genera which have been proposed.

The larvae of the Trombiculidae are distinguished by having only a single anteriorly placed dorsal shield, of varying shape, from rectangular to pentagonal, hexagonal or tongue-like, and furnished normally with 1 or 0 antero-median setae, 2 antero-lateral setae and 2 postero-lateral setae, as well as a pair of sensillae which may be filamentous, clavate or globose. Additional setae may occasionally occur on those scuta which are more or less tongue-shaped, but these setae are usually situated behind the postero-lateral setae. Eyes may be 1 or 2 on each side or absent. Coxae I are furnished with only a single seta, and there is a pair of setae between these coxae. The legs are all furnished with a pair of simple claws and a longer and more slender empodium.

The larva of *Blankaatia nilotica* (Träg.) has many characters which place it outside the family Trombiculidae as defined above. In the first place it has two antero-dorsal shields, the front one of which is large and reaches or overlaps the anterior margin of the body and is furnished with 6 setae in addition to the filamentous sensillae. The second shield has a number of setae. The pair of setae, normally between coxae I have migrated onto the coxae so that each carries 2 setae. Legs I and II have only the paired claws, and no empodium, the claws being apically furcate. On leg III the claws have an apical nail-like tip.

* Entomologist, South Australian Museum.

Thus, while the adult *Tragardhula nilotica* (Träg.) belongs to the Trombiculidae, the larva certainly does not, and the two stages described by Trägårdh under this name cannot be associated.

In 1936 Sig Thor (Zool. Anz. **114**, 30) raised the genus *Pentagonella* for those species of larval Trombidiids in which the dorsal scutum was pentagonal in shape, and the sensillae filamentous. As type he designated *Trombidium ardeae* Träg. from the White Nile. Other species were *fahrenholzi* (Ouds. 1910), *tragardhi* (Ouds. 1910), *muris* (Ouds. 1910), *acuscutellaris* (Walch 1922) and *yorkei* (Sambon 1928).

This genus has been rather ignored by most workers, but Willmann in 1947 (Das Tierreich, Lfg. 71 b, Trombidiidae, p. 292) admits it, and includes the additional species *desaleri* (Methlagl. 1928) and *centropodis* (Ewing 1928). Until now, no adults of any of these species have been known, but in this paper adults of *P. acuscutellaris*, both caught in the field and reared from larvae through several generations are described, and it is shown that they agree fully with the subgenus *Tragardhula* Berlese.

The subgenus *Megatrombicula* was erected in 1947 by Michener (Ann. Entom. Soc. Amer., **39**, 432) for four species of adult Trombiculids from Central America. The subgenotype was *Trombicula allcei* Ewing, and other included species were *T. velascoi* (Boshell and Kerr), *T. peruviana* (Ewing) and *M. attenuata* Michener.

The essential character of the subgenus was the position of the eyes, well away from the crista and well anterior of the sensillary area. Michener was also successful in obtaining larvae of these species, except *peruviana*, and although he could only separate these with difficulty, he pointed out their great similarity to *Pentagonella* of the Old World in their having a pentagonal scutum.

In 1916 Tanaka (Zentbt. Bakt., Abt. 1, Orig.) refers to, and on pl. 4, fig. 37, shows clearly, the position of the eyes as well away from the crista and in advance of the sensillary area in a nymph of *Trombicula japonica*, then referred to a subspecies of *autumnals* (Shaw), which is not related in that the eyes in the latter species are entirely wanting.

The following description of the adult of *P. acuscutellaris* fits clearly those of *Megatrombicula* and *Tragardhula*, and both *Pentagonella* and *Megatrombicula* therefore are synonymous with *Tragardhula* Berl. The fact that *acuscutellaris* is the only species of *Pentagonella* from the Old World as yet known from the adult, but is not the actual genotype of *Pentagonella*, leaves a slight possibility that the adult of *ardeae* (the genotype) may not be a *Tragardhula*. However, it having been shown that *Blankaartia nilotica* (Ouds.) is not related to *Tragardhula nilotica* (Berl.), can any other Egyptian larval *Trombicula* with pentagonal scutum be suggested as the possible larvae of *Trag. nilotica*? Of such larvae only two have been described from Egypt, *T. ardeae* and *T. tragardhi* (Ouds. 1910), both from Trägårdh's expedition.

The first of these was from the legs of a heron, *Ardea cinerea*, from the White Nile, March 1901, the same locality and date as for *Trag. nilotica*. While the association of this larva with the adult cannot be accepted until successful rearings have been made, the habitat of the larvae on the legs of a *wading* bird, and the adults on the leaves of an aquatic plant (*Pistia*) is highly suggestive.

The second species of larvae, *tragardhi* (Ouds.) was from the ears of a monkey, *Cercopithecus*, and thus from such a host habitat can, surely, be disregarded.

Genus TRAGARDHULA Berlese 1912

Tragardhula Berl. 1912, Redia, 8, 4; *Blankaartia* Berl. 1912, Redia, 8, 96 (non Oudemans 1911 larvae); *Pentagonella* Sig Thor 1936, Zool. Anz., 114, 30; *Megatrombicula* Michener 1947, Ann. Entom. Soc. Amer., 39, 432.

Adults of typical *Trombicula* figure of 8 facies. Crista linear with sub-posterior sensillary area about as wide as long. Epistome rounded with fine teeth and 1 seta. Accessory spines on palpal tibia arising from a slightly raised boss some distance from base of claw. Eyes large, 1 + 1, well separated from crista and well in front of sensillary area. Sternal plate distinct and well defined, undivided, wider than long and lying between coxae I.

Genotype: *Trombidium niloticum* Träg., adult.

TRAGARDHULA ACUSCUTELLARIS (Walch 1922)

Trombicula acuscutellaris Walch 1922, Kitasato Archiv. Exper. Med., 5, (3) 78; Gater, B. A. R., 1932, Parasitol., 24, 143-174; Mehta, D. A., 1937, Ind. J. Med. Res., 25, (2), 353-365; Philip, Woodward and Sullivan 1946, Amer. J. Trop. Med., 26, (2); Radford, C. D., 1946, Parasitol., 37, (1-2); Jayewickreme, S. H., 1947, Nature, 160, 578.

Trombicula (Pentagonella) acuscutellaris, Sig Thor 1936, Zool. Anz., 114, 30; Womersley and Heaslip 1943, Trans. Roy. Soc. S. Aust., 67, (1), 78.

Tragardhula acuscutellaris, Willmann 1947; Das Tierreich, Lfg., 71 b.

This species is widely distributed in the Asiatic-Pacific Region. It was originally described by Walch from Sumatra, and has since been reported from the Federated Malay States (Gater), India (Mehta), Maldive Islands (Radford), Ceylon (Jayewickreme), and I have seen material collected by Lieut.-Col. C. B. Philip from the Philippines, and by Maj. R. N. McCulloch from Borneo. In all cases the hosts of the larvae were species of *Rattus*. The nymphal stage of this mite remained unknown until 1946 when Radford described very briefly the nymph reared from larvae. The adult remained quite unknown and unrecognised in the field until last year when Jayewickreme reported in "Nature" the successful rearing through several generations, using the recently established methods of feeding the nymphs and adults on the eggs of species of mosquitoes. Further, the adults can now be fairly easily recognised in the field, and large numbers of larvae have been obtained from captured females.

In the present work the adult male and female are described and figured for the first time, and the opportunity is taken of redescribing and figuring the larva and nymph more fully. For the material for this study I am very much indebted to Mr. S. H. Jayewickreme who very willingly supplied me with a considerable amount of both reared and wild larvae and adults. The redescription of the nymph is from a specimen supplied by Dr. C. D. Radford.

Redescription of Larvae. Fig. 1, A-F—Colour in life red. Shape oval. Length unengorged 260 μ (excluding gnathosoma), width 195 μ. Dorsal shield (fig. 1, D) pentagonal, with PW only very slightly greater than AW, and angle of convexity of posterior margin, *i.e.*, PW/PSB = 2·0 or thereabouts. Sensillae long and filamentous with ciliations in distal two-thirds. Normal setae of scutum and dorsal setae ciliated and tapering. Eyes 2 — 2, on ocular shields, the posterior eyes the smaller. Palpi (fig. 1, E) stout; femur and genu furnished with a branched or long ciliated seta; tibia with the normal 3 setae, of which the ventral has branches, the dorsal and lateral being nude; palpal claw trifurcate. Chelicerae (fig. 1, C) with the usual apical tricuspid cap, and on the inner edge a subapical forwardly directed tooth. Galeal setae nude. Dorsal setae 26 in number, arranged 2.6.6.6.4.2 (fig. 1, A). Ventral setae, excluding the single one on each coxa, 24, arranged 2.2.6.4/4.4.2 (fig. 1, B). Dorsal setae to 70 μ long, ventral to 50 μ. Legs long and

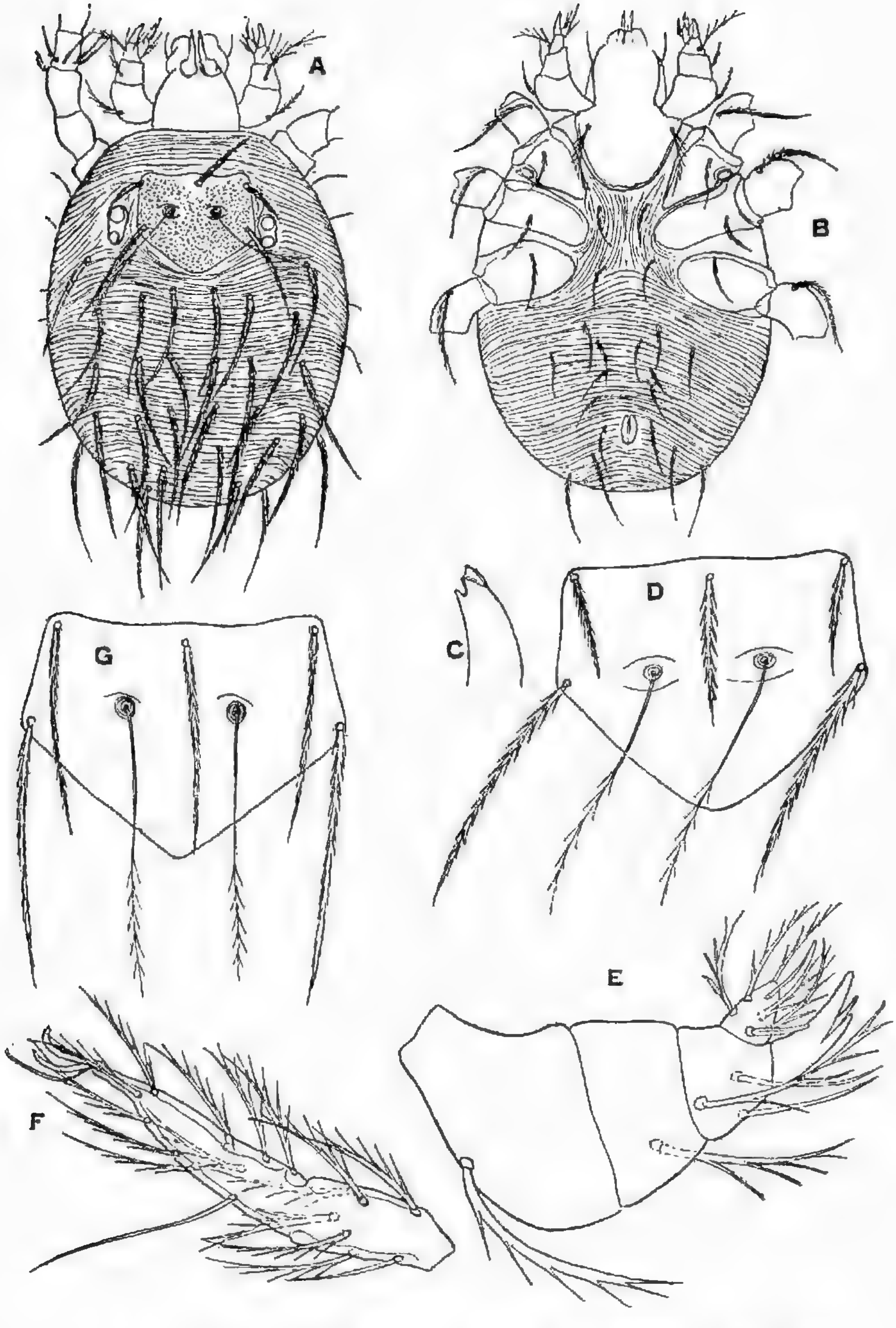


Fig. 1, A-F—*Tragardhula acuscutellaris* (Walch 1910) larvae. A, dorsal view; B, ventral view; C, tip of chelicera; D, scutum (x 500); E, palp in ventral-lateral view; F, tarsus and metatarsus of leg III; G, scutum of larvae of *Tragardhula* (*Pentagonella*) *ardeae* (Trägårdh) (x 500).

slender, all 7-segmented, I to 330 μ long (including coxa), II 312 μ, III 435 μ; tarsi I and II with the usual dorsal sensory rod, III (fig. 1, F) with a long subbasal fine nude seta to 80 μ in length.

The Standard Data derived from 17 specimens from eggs laid by a wild adult from Ceylon, 17 December 1947 (S. H. Jayewickreme), and one specimen each from Federated Malay States and from Batavia reported upon in 1943 (Womersley and Heaslip), and one specimen from *R. r. norvegicus* from the Maldive Islands, 30th December 1944 (C. D. R.) are as follows:

	Mean	Standard Deviation	Theoretical Range	Observed Range	Coeff. of Variation
AW	77·4 ± 0·58	2·61 ± 0·41	69·6 – 85·2	70·0 – 84·0	3·3
PW	80·1 ± 0·55	2·47 ± 0·39	72·7 – 87·5	75·6 – 86·8	3·1
SB	30·8 ± 0·27	1·20 ± 0·19	27·2 – 34·4	28·0 – 33·6	3·9
ASB	30·0 ± 0·28	1·24 ± 0·19	26·3 – 33·7	28·0 – 30·8	4·1
PSB	43·3 ± 0·32	1·43 ± 0·22	39·0 – 47·6	42·0 – 44·8	3·3
SD	72·3 ± 0·46	2·04 ± 0·32	66·2 – 78·4	70·0 – 75·6	2·8
A-P	25·9 ± 0·26	1·16 ± 0·18	22·4 – 29·4	25·2 – 28·0	4·5
AM	52·7 ± 0·49	2·04 ± 0·35	46·6 – 58·8	50·4 – 56·0	4·0
AL	40·25 ± 0·61	1·56 ± 0·25	35·5 – 44·9	39·2 – 43·4	3·8
PL	77·1 ± 0·61	2·68 ± 0·43	69·1 – 85·1	75·6 – 85·1	3·5
Sens.	84·0		No variation recorded		

Redescription of Nymph, from a specimen reared from larvae by C. D. Radford in the Maldive Islands.

Colour in life bright red. Of typical *Trombicula* facies. Length to 800 μ, width across hysterosoma 400 μ. Crista linear with somewhat diamond-shaped areola, and two filamentous nude sensillae, 136 μ long, sensillae bases 42 μ apart. Eyes 1 + 1, well removed from sensillary area and about half-way between extremes of crista. Chelicerae normal with fine inner serrations. Palpi with tibial claw strong, with 2 accessory spines but these on a slight boss and placed about midway between base of claw and articulation of palpal tarsus. Palpal tarsus slightly clavate, not reaching tip of claw. Legs: shorter than body, I 660 μ long, II 460 μ, III 470 μ, IV 530 μ; tarsus I less than twice as long as wide, 151 μ by 91 μ, metatarsus I 115 μ long. Dorsal setae numerous 40 μ long, uniform, arising from closely set tubercles, uniformly thick with strong ciliations. Genital discs 2 pairs.

Description of Adult—Fig. 2 A-J. No apparent difference in the size of males and females. Colour in life deep red. Of typical *Trombicula* facies. Length to 1,800 μ, width across hysterosoma 1,200 μ. Crista (fig. 2 A) linear with well-developed subposterior sensillary area, roughly diamond-shaped, with the sensillae bases at the ends of transverse dumbbell-shaped areola; crista 300 μ long and sensillae bases 65 μ apart; sensillae 195 μ long, filamentous and nude; apex of crista forked. Epistome well developed, rounded conical with numerous teeth and with a single seta 71 μ long. Eyes 1 + 1, large, situated well away from crista and midway of crista length. Chelicerae (fig. 2 B) with finely-toothed inner edge. Palpi (fig. 2 C and D) with strong tibial claw and 3 accessory spines which are distinctly away from base of claw, and another on outer edge opposite articulation of tarsus, and on the outer surface another strong spine. Legs normal, I 1,275 μ long, II 910 μ, III 910 μ, IV 1,235 μ; tarsus I (fig. 2 I) 325 μ long by 163 μ high, metatarsus I 247 μ long; sternal shield between epimera of legs I and

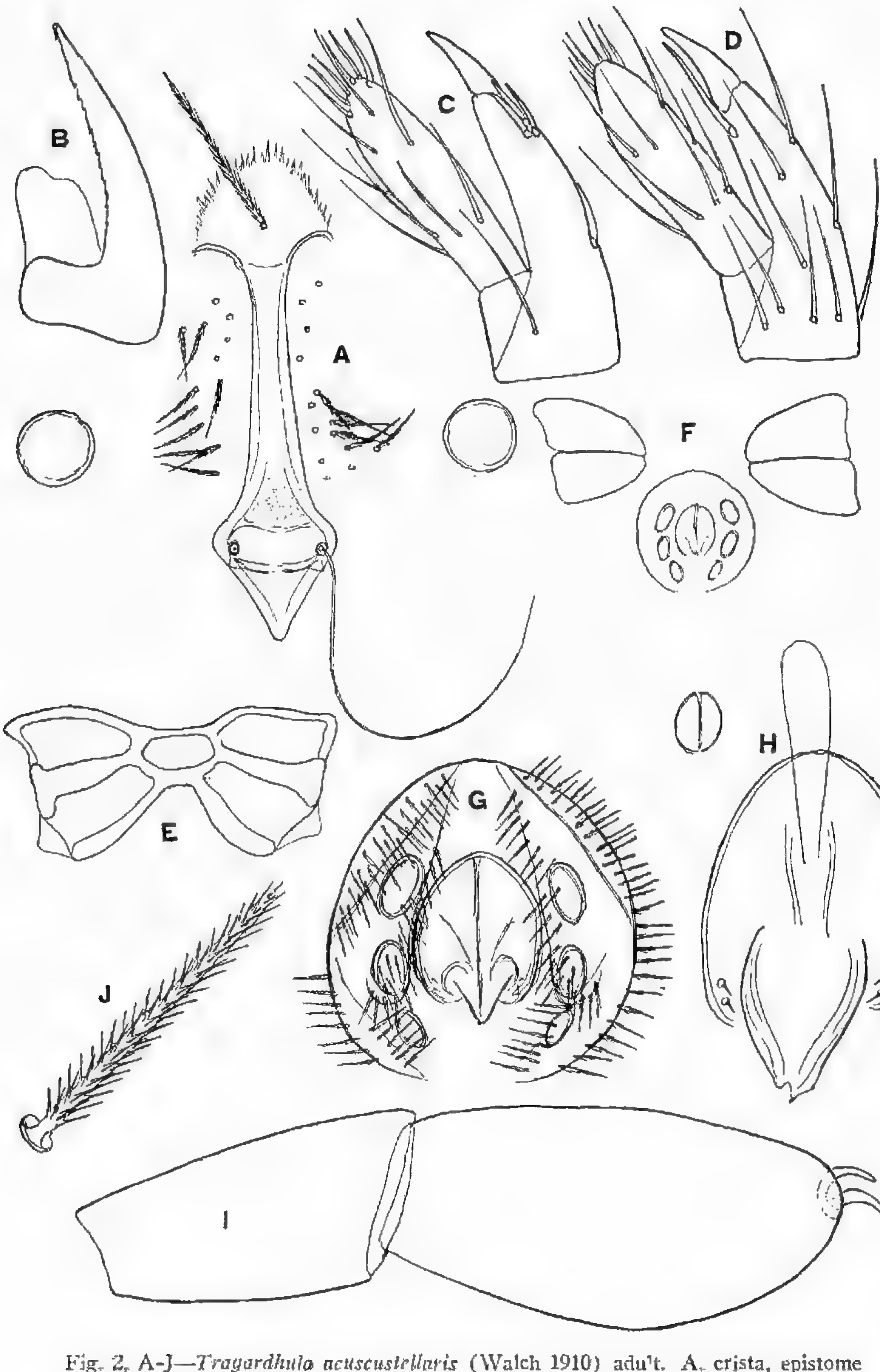


Fig. 2, A-J—*Tragardhula acuscustellaris* (Walch 1910) adult. A, crista, epistome and eyes; B, chelicera; C, palpal tibia and tarsus from above; D, ditto from below; E, coxae I and II and sternum; F, coxae III and IV with genitalia and anus showing relative positions; G, genitalia of male; H, penis; I, tarsus and metatarsus of leg I; J, posterior dorsal seta.

II, markedly shorter than wide (fig. 2 E). Genital orifice situated close into the epimera of legs III and IV (fig. 2 F), with 3 pairs of genital discs. In the male provided with a penis as figured (fig. G and H), the apical point of which is asymmetrical. Dorsal setae numerous, uniformly thick, with short ciliations (fig. 2 J).

The synonymy of *Tragardhula nilotica* (Träg. 1904) is as follows: ? *Trombidium ardeae* Trägårdh 1904; *Microtrombidium a*, Ouds. 1910, *M. a.*, Ouds. 1912; *Trombicula a.* Ewing 1928; *Pentagonella a.* Sig. Thor 1936, *P. a.* Willmann 1947 (larvae); *Trombidium niloticum* Trägårdh 1904; *Trombicula* (*Tragardhula*) *n.* Berlese 1912, p. 4; *Trombicula* (*Blankaartia*) *n.* Berl. 1912, p. 96 (non *Blankaartia* Ouds. 1911, larvae); *Tragardhula n.* Willmann 1947.

The following table shows the adult or nymphal species which belong to the genus *Tragardhula* and the larval species which will possibly also be placed therein as their respective adults are discovered.

Other species of *Trombicula* are known which in the larvae have a more or less pentagonal scutum but do not fit with any certainty into *Tragardhula*; for example *T. autumnalis* of Europe, in which the adult has no eyes and belongs to a group for which the name *Neotrombicula* Hirst is available.

ADULTS OR NYMPHS

Trag. nilotica (Trägårdh 1904)	*Trag. attenuata* (Michener 1947)
Trag. acuscutellaris (Walch 1922)	*Trag. japonica* (Tanaka 1916)
Trag. peruviana (Ewing 1926)	*Trag. alleei* (Ewing 1926)
	Trag velascoi (Boshell and Kerr 1941)

LARVAE

Trag. alleei (Ewing 1926)	*Trag. fahrenholzi* (Ouds. 1910)
Trag. velascoi (Boshell and Kerr 1941)	*Trag. muris* (Ouds. 1910)
Trag. ardeae (Trägårdh 1904)	*Trag. desaleri* (Methlagl. 1928)
Trag. tragardhi (Ouds. 1910)	*Trag. japonica* (Tanaka 1916)
Trag. yorkei (Sambon 1928)	*Trag. acuscutellaris* (Walch 1922)
Trag. centropodis (Ewing 1928)	*Trag. attenuata* (Michener 1947)

TRAGARDHULA ? (PENTAGONELLA) ARDEAE (Träg.)

Prof. Ivar Trägårdh, whom I recently had the very great pleasure of meeting in Stockholm, has very kindly loaned to me for study a number of slides of his (1901) Egyptian material. One slide contained 4 specimens of his *ardeae*. These have been remounted, and I am now able to give the following data to bring the description into line with recent studies on the species of larval Trombiculidae.

Fig. 1, G—Dorsal scutum pentagonal with PSB greater than ASB, and SB about in line or slightly in advance of PL. Eyes 2 + 2, closely adjacent to postero-lateral angles. AM and AL about equal, PL much longer. Sensillae filamentous and ciliated on distal half. Chelicerae with the usual apical tricuspid cap only. Palpi stout, tibial claw trifurcate with the prongs subequal; setae on femur and genu with branches; on tibia ventral strongly branched or ciliated, lateral lightly branched, dorsal nude. Galeal setae with 2 or 3 light branches. DS long, to 84 μ, arranged 2.6.4.8.6.4. Ventral setae rather shorter, arranged 2.2.6.6.2.4.2. Tarsus of leg III with a long nude seta; of leg I and II with the usual dorsal rod-like sensilla.

Standard Data in microns from 4 specimens are:

	Mean	Standard Deviation	Theoretical Range	Observed Range	Coeff. of Variation
AW	74·2 ± 1·4	2·80 ± 0·99	65·8 – 82·6	72·8 – 78·4	3·8
PW	87·5 ± 0·7	1·40 ± 0·49	83·3 – 91·7	86·8 – 89·6	1·6
SB	31·85 ± 0·35	0·70 ± 0·24	29·75 – 33·95	30·8 – 32·2	2·2
ASB	25·2	No variation recorded			
PSB	42·0	No variation recorded			
SD	67·2	No variation recorded			
A-P	28·0	No variation recorded			
AM	61·6	No variation recorded			
AL	60·7 ± 0·93	1·62 ± 0·65	55·9 – 65·5	58·8 – 61·6	2·6
PL	84·0	No variation recorded			
Sens.	84·3 ± 2·6	4·51 ± 1·84	70·8 – 97·8	80·0 – 89·0	5·3

THE PLANT ECOLOGY OF PART OF THE MOUNT LOFTY RANGES (1)

By R. L. Specht and R. A. Perry

Summary

This paper deals with the ecology of that part of the Mount Lofty Ranges between the Torrens Gorge in the north and Noarlunga in the south.

THE PLANT ECOLOGY OF PART OF THE MOUNT LOFTY RANGES (1)

By R. L. Specht and R. A. Perry *

[Read 10 June 1948]

Contents

* Department of Botany, University of Adelaide.

INTRODUCTION

This paper deals with the ecology of that part of the Mount Lofty Ranges between the Torrens Gorge in the north and Noarlunga in the south.

The area surveyed by Specht lies between the Torrens Gorge in the north, grid line 80 of the Adelaide and Echunga ordnance map in the east and grid line 68 in the south, while Perry surveyed the area from grid line 68 in the north to 52 in the south extending east from the coast to grid line 68.

The only previous ecological work on this area was a reconnaissance survey by Adamson and Osborn (1). As can be expected from reconnaissance survey, some generalisations were made which probably apply to part of the Mount Lofty Ranges but not necessarily to the whole. Adamson and Osborn did not publish any vegetation map, nor did they indicate in the text the exact localities studied. Since then detailed work on the soils of the southern portion of the Hundred of Kuitpo, by Taylor and O'Donnell (21) and on the geology by Sprigg (17, 18, 19) form a useful background to this study of ecology.

Considering the limited size but complexity of the area, it was deemed necessary that the ecology should be approached from a study of the autecology of the dominant tree species and of the formations. With this in view the distribution of the tree species and formations was mapped by projecting their limits on a contour map. As many factors as possible of the environment were examined and attempts were made to correlate the distribution of the species with the environment. The soils were surveyed by borings at each grid intersection on the ordnance survey maps, i.e. at approximately 1,000 yard intervals.

Because of the complexity of the environment the study of the vegetation could be regarded as a number of specially designed experiments in which possibly only one factor at a time was variable. For instance, it was found that soils of different nutrient status occurred contiguously under the same climatic conditions, while soils of one group extended from regions of low to high rainfall. Of course, any generalisation can only be accepted on the understanding that it may not necessarily apply to other areas of the Mount Lofty Range. However, although other surveys of the ecology of this State have been of rather a broad nature in comparison, they have yielded conclusions roughly similar to some suggested in this survey. These have been indicated in their appropriate places within the text. It must be pointed out that in dealing with the trees whose roots tend to penetrate to great depth, the early stages of growth are considered crucial in their development within the environment in which they are found.

As most of the soils throughout the area are extremely poor most of the area has been left relatively undeveloped. It is only along the coastal parts in the south, the Adelaide Plains and fertile valleys and ridges of the Hills, that much agricultural development has taken place. Most of the soils of the coastal area are planted with vineyards and orchards, but some cereals are grown. The Adelaide Plain, although now closely settled, was once an extensive cereal growing area, while the small fertile portions of the hills are planted with orchards, vegetables and some pastures. The savannah woodlands are used in their natural state for grazing.

TOPOGRAPHY

The area forms part of an original extensive peneplain which has been block-faulted during the Kosciuskan period (probably Pleistocene) and subsequently dissected by three major stream systems—namely from north to south, the Rivers Torrens, Sturt, and Onkaparinga.

Creeks named First, Second, Third, Fourth, Fifth and Sixth Creek form the major tributaries of the River Torrens, and Cox's, Aldgate and Scott's Creeks flow into the River Onkaparinga. Both the River Torrens and the Onkaparinga are part of the old river systems present before the faulting occurred. They must have been large enough to keep pace with the rise in level due to faulting and have cut meandering gorges up to 500 feet in depth. Smaller creeks such as Brownhill, Christie's and Reynella Creeks aid the drainage of the area.

In the southern section of the area three distinct faults are present. The land rises sharply from the gently rising Adelaide Plains along the Eden

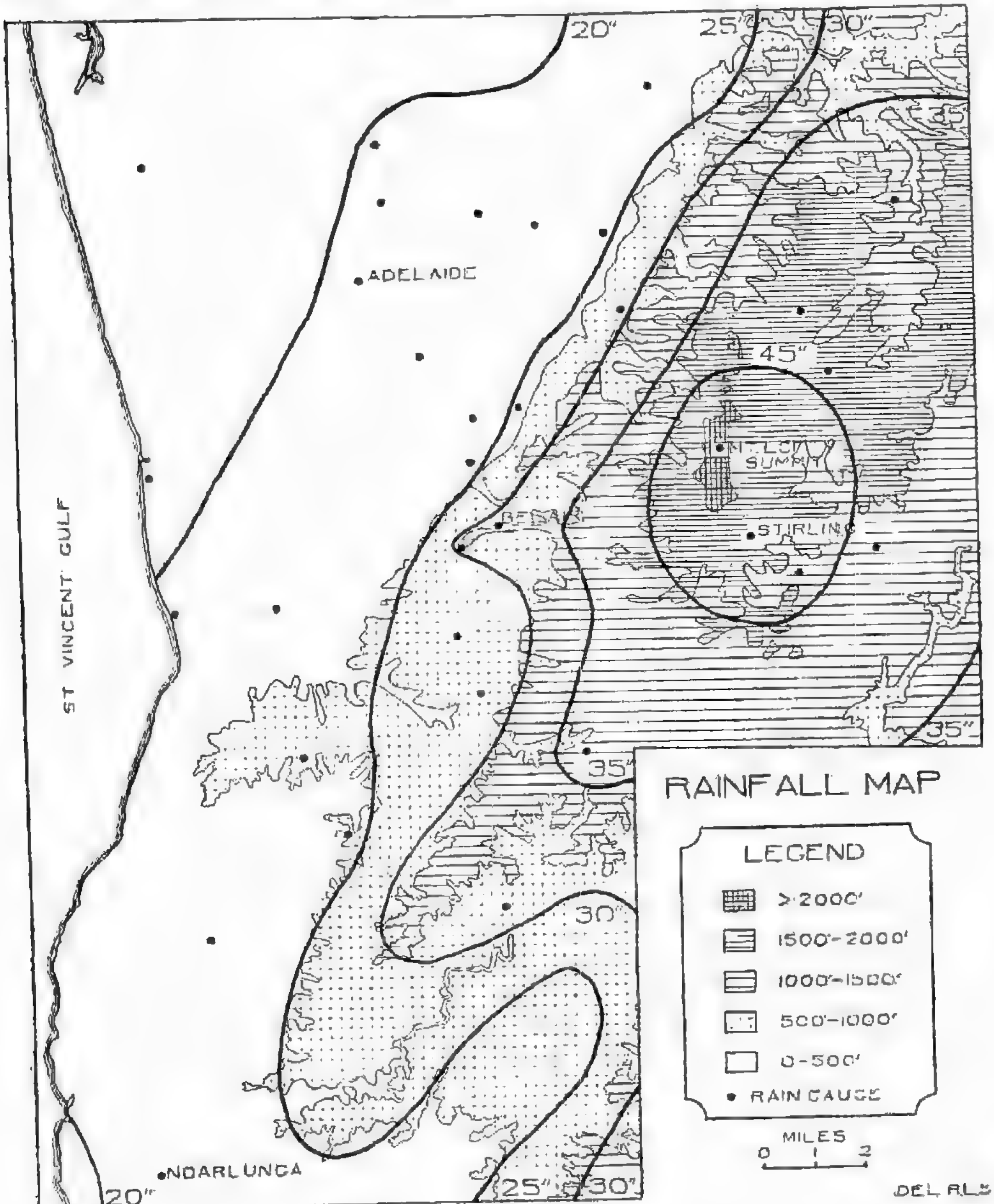


Fig. 1
Rainfall and altitude map.

fault (with a throw of 600 to 700 feet) on to the Eden-Moana Block, again at the Ochre Cove Fault Block and still again with a throw of 700 feet along the Willunga Fault. The original peneplain level gradually slopes to the south-west along these three fault blocks, the level of the Ochre Cove Fault Block in particular dropping from 1,200 feet north of Clarendon to 400 feet near Noarlunga. In the northern section, however, only the Eden Fault is prominent but the topography is complicated by the indistinct extremities of the Ochre Cove and Kitchener Faults, while the Burnside Fault occurring a little to the west of the Eden Fault aids in confusion. The monadnock structure of Mt. Lofty, which rises to 2,234 feet, dominates the topography.

A general idea of the topography can be gained from the rainfall map on which contours for the 500 feet level and multiples thereof are indicated (Fig. 1). The dissection is influenced by the nature of the rock, the slates and phyllites giving more rounded and gentler sloping ridges than those developed in the less rapidly weathering quartzites. Plate V shows a photograph of a model made of the central section of the area.

GEOLOGY

Sprigg's Reconnaissance Survey of the Geology of the Mt. Lofty Ranges (between the rivers Sturt and Torrens) (19) and the Geology of the Eden-Moana Fault Block (17) gives a detailed account of the geology of the area.

The undermass rocks consist of a series of Pre-Cambrian sediments, called the Adelaide Series, which have been extensively faulted and folded.

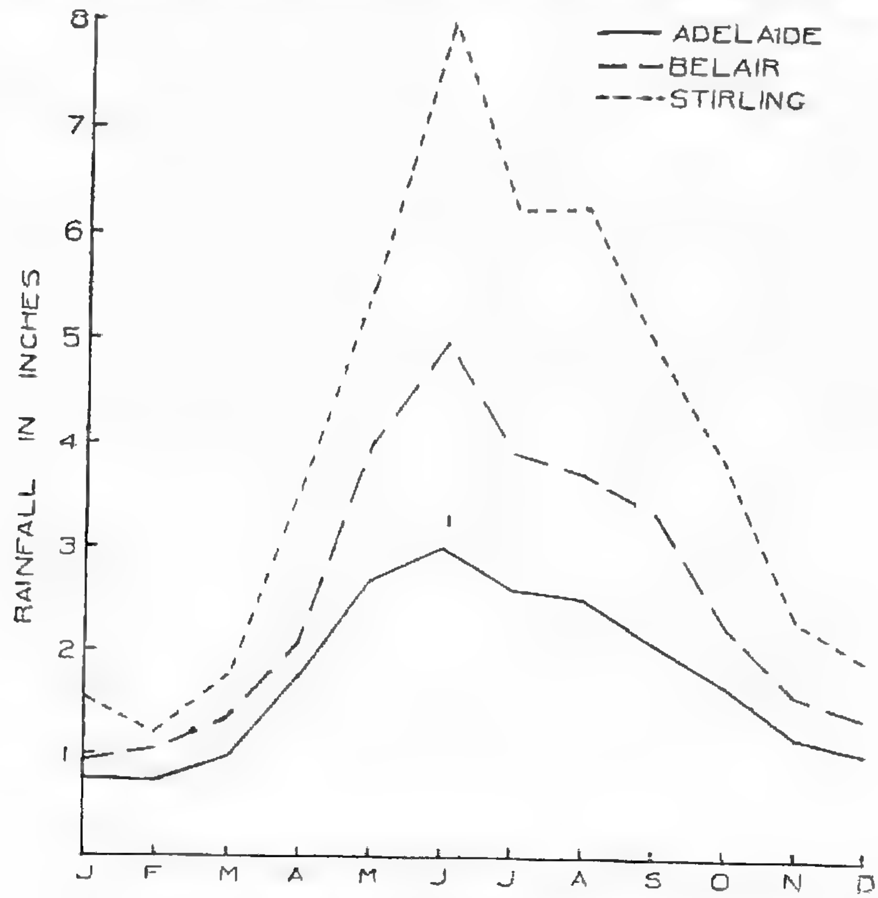


Fig. 2

Mean monthly rainfall at Adelaide, Belair and Stirling.

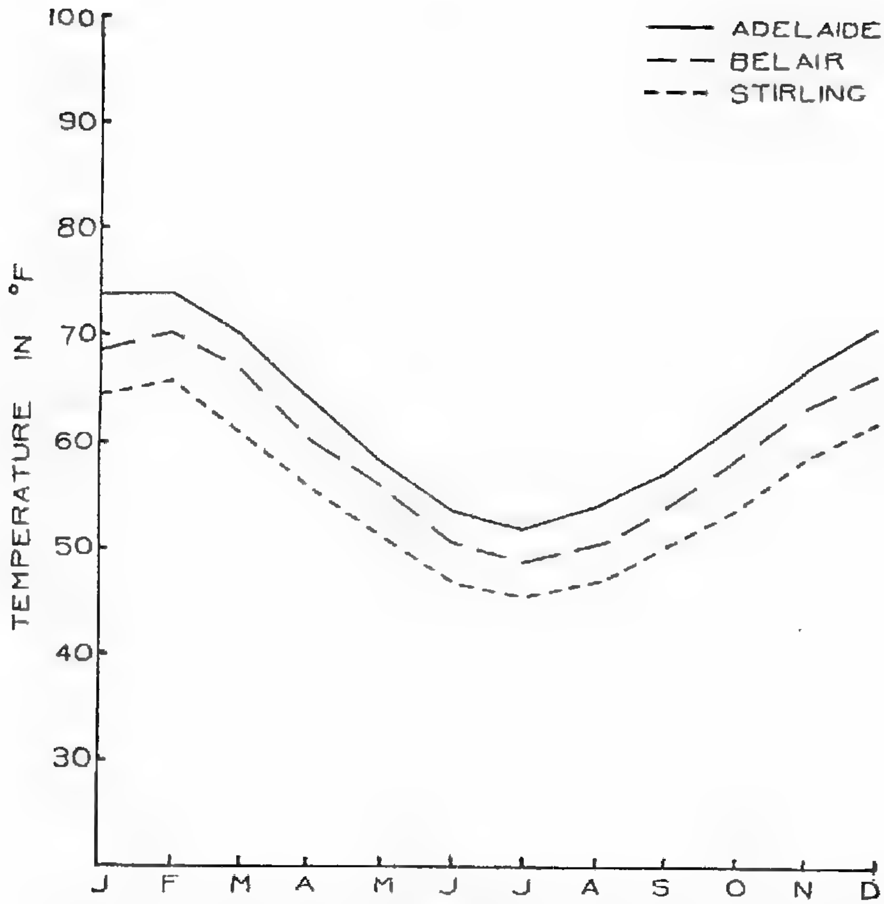


Fig. 3
Mean monthly temperature at Adelaide, Belair and Stirling.

Of importance to the ecology of the area are the metamorphosed rocks of the Barossian Complex, the sandstones, quartzites and phyllites of the Lower Adelaide Series (the easterly half of the area) and the slates, Sturtian tillite and flaggy slates and quartzites of the Upper Adelaide Series (the westerly half).

Overlying the Adelaide Series on the Eden-Moana Fault Block from Blackwood to Happy Valley Reservoir are remnants of a lacustrine deposit of consolidated Oligocene sands on the old peneplain surface. In addition large areas of Miocene marine sediments, mainly marls and limestone, and limited areas of Pleistocene raised sea beaches occur on this block.

Since the Pleistocene the Torrens River and Brownhill Creek systems have built up the large alluvial deposits of the Adelaide Plain with material dissected from the fault blocks to the east.

In recent times the River Onkaparinga has developed an extensive alluvial flood plain which extends several miles inland from its mouth.

CLIMATE

The meteorological data available from stations within and adjacent to the area suggest that there is a close correlation between altitude and climate. Rainfall data indicate an increase in rainfall with altitude (see rainfall map) rising from 17·94 inches per annum at Glenelg to 47·84 inches

per annum on Mt. Lofty Summit, with a deterioration in rainfall to the north and in the rainshadow of Mt. Lofty Summit. This deterioration is caused by the fact that most rains are borne by south-west winds. In all cases February is the driest while June is the wettest month. The data available for Adelaide, Belair and Stirling West show that there is an increase in rainfall and humidity and a corresponding decrease in temperature with altitude (see Figs. 2 and 3).

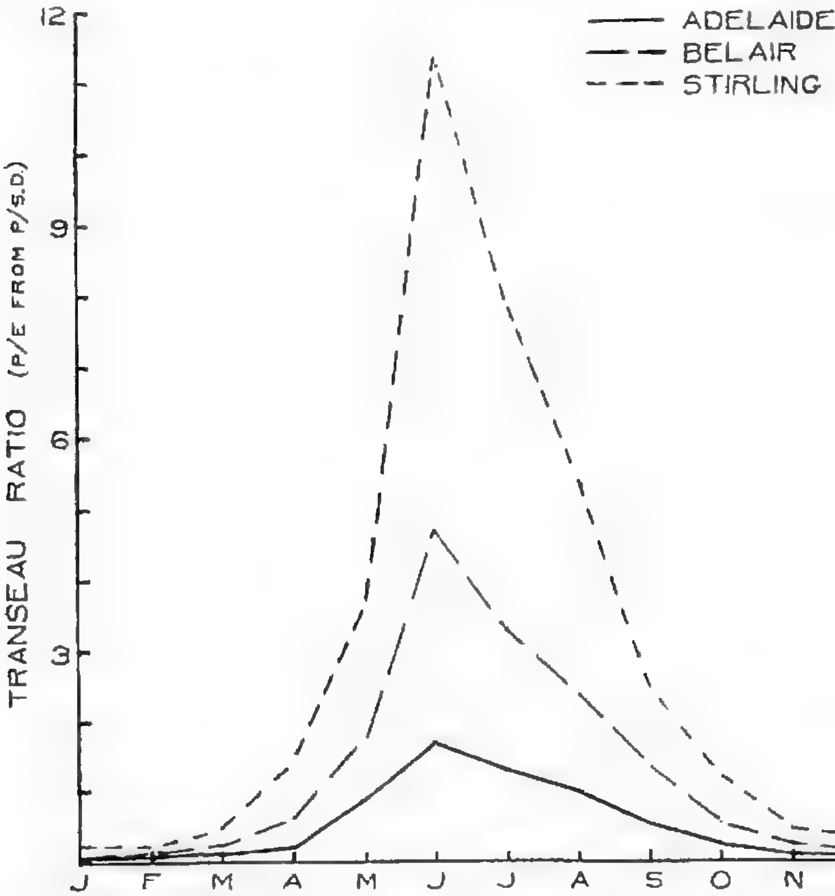


Fig. 4
Mean monthly values for Transeau ratio at Adelaide, Belair and Stirling.

From the average humidity and average temperature, the Meyer and Transeau ratios have been calculated, both of which show an increase with altitude (see Fig. 4). From this data it is seen that Adelaide has an influential rain period (P/E greater than 1/3) for 6·8 months, Belair for 8·5 months and Stirling West for 10·7 months with influential rainfalls of 15·9 inches, 26·3 inches and 45·8 inches respectively (Trumble 23). When Davidson's less accurate P/E greater than 1/2 is used, Adelaide lies within Davidson's warm temperate semi-arid zone while Belair and Stirling West lie within his warm temperate semi-humid zone (10). However, it must be remembered that all the above data give a rough approximation only of the moisture relations within the soil, for the dissection of the country and the water-retaining capacity of the soils play a large part in producing microclimates. Much of the influential rains is lost to the soil as "run-off" into the creeks, which consequently are moister habitats, while a clay soil will tend to retain more moisture than a sandy soil in which most of the

water percolates through into the subsoil or to the underlying rock. Hence under the same conditions of physiography and climate a deep sand will tend to be drier than a shallow sand over a clay subsoil which in turn will tend to be drier than a soil with a predominantly clayey profile. It must also be remembered that Trumble (23) in proposing his influential rainfall period as those months with P/E greater than 1/3, based it on the time interval over which the surface soil of the Waite Agricultural Research Institute tends to be maintained above the wilting point for herbage plants. It does not necessarily follow that the same factor of 1/3 holds for all other plants and seedlings.

Insolation has a marked influence in producing microclimates in dissected country; that is the micro-climates are also determined by aspect. Although no attempt has been made to demonstrate this for the Adelaide Hills, the southern sides of the ridges are apparently moister than the northern sides. This is largely due to the direct effect of insolation on evaporation—the sunny, warmer, north-facing slope being drier than the more shaded, cooler, south-facing slope. This difference in micro-climate may also be enhanced by the fact that most of the rain is borne from the south-west (this data is available only for Adelaide but should be similar for the rest of the area), hence giving a minor rain-shadow on the northerly sides of the ridge.

Consequently, with the decrease in temperature with altitude, the figures for Adelaide, Belair and Stirling West indicate that active growth of herbage plants (average monthly temperature less than 55° F) is restricted for 3, 4 and 6 of the winter months respectively, and moderate growth (less than 50° F.) for nil, 1 and 3 months respectively. (Trumble 23).

Hours of sunlight and frosts appear to have little effect on the general vegetation, but may play a part in the agriculture of the area.

From the data presented above it is evident that the area can be roughly divided into at least three main climatic regions, namely:

(1) Country less than 500 feet altitude with an influential rainfall period of 6 to 7 months.

(2) Country 500 to 1,500 feet altitude with an influential rainfall period of 7 to 9 months.

(3) Country greater than 1,500 feet altitude with an influential rainfall period of 9 to 11 months.

with a large number of micro-climates produced within each zone.

SOILS

In the southern two-thirds of the area a reconnaissance was made of the pedology by boring holes approximately 1,000 yards apart, while the remainder of the area was mapped from observations made on profiles exposed in cuttings and by a superficial examination of the soil. As the survey was on a broad scale no attempt has been made to map soil types, the survey being only sufficient to give an outline of the soil groups present.

Where the rocks of the Adelaide Series or overmass sediments are exposed there is a marked correlation between the geology and the soil while. in the south, soils derived from lateritic soils developed on the former peneplain surface tend to predominate.

The soils can be grouped as follows:—

A. Soils derived from Plio-Pleistocene lateritic soils:

  (1) Residual lateritic podsols.

  (2) Truncated lateritic podsols.

(3) Deep siliceous sands with strongly acid reaction.
(4) Lateritic podsols under conditions of poor drainage.

B. Soils formed under the present environmental conditions:
  (1) Podsols.
  (2) Grey-brown podsols:
    (a) With high nutrient status.
    (b) With low nutrient status.
  (3) Calcimorphic soils:
    (a) Rendzinas.
    (b) Terra rossas.
    (c) Degraded rendzinas.
  (4) Red-brown earths.
  (5) Ferrimorphic soils (?).
  (6) Deep sands of neutral reaction.
  (7) Miscellaneous soils.

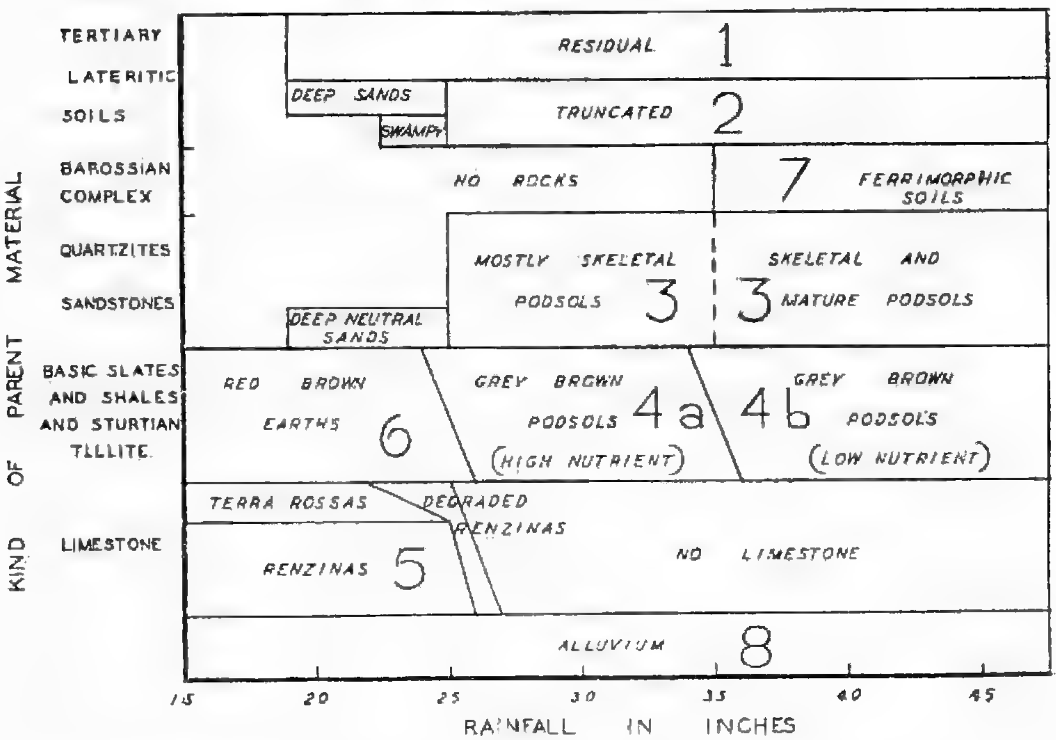


Fig. 5

Diagram showing the soils in relation to rainfall and parent material.

The relation of the soils to rainfall and parent material is illustrated in fig. 5. The parent materials are arranged from bottom to top in decreasing order of base content. Thus, generally, the soils at the top of the diagram have a lower nutrient status and a lower pH than those at the bottom. For the purpose of the diagram, the Tertiary lateritic podsols are regarded as the parent material from which the present-day lateritic soils have been derived.

A. Soils derived from Plio-Pleistocene Lateritic Soils

These soils are relics from a more pluvial climate in the Pliocene when they were developed over most of the former peneplain surface. The profile developed during this period is that of a highly leached podsol in which a seasonally fluctuat-

ing water-table produced concretions of ferruginous material near the junction of the sand and the clay horizons. Often ferruginisation appears as pockets through the clay and the parent material (Stephens 20). The lateritic concretions show great variation. In some cases they are massive while, in others, pisolitic gravel and nodules occur. Over the Oligocene lacustrine deposits a ferruginised sandstone or a ferruginised conglomerate of water-worn quartz pebbles occurs in the position of the lateritic concretions in the typical lateritic profile.

However, when faulting broke up the old land surface in the Pleistocene, dissection began and the lateritic profile was truncated to varying degrees. Over most of the area, especially in the northern half, complete truncation down to the parent rock has occurred. Evidence of the former lateritic profile is frequently seen by intense ferruginisation of the rock on the tops of the ridges. These rocks thus exposed have developed soils in equilibrium with the present climate (see below).

Lateritic soils in varying stages of truncation occur on the tops of the ridges which constitute the former peneplain level on the Eden – Moana, Ochre Cove and Willunga Fault Blocks. As shown in the section on topography, all these fault blocks are tilted to the south-west. On the Eden – Moana Fault Block complete truncation of the lateritic profile occurs in its northern limit. At Belair the profile is truncated down to the lateritic gravel (a truncated laterite), the sand of the A horizon having drifted down the gradient to the south-west, or eroded down the valley. At Blackwood a little to the south a shallow sandy A horizon is present, this horizon becoming deeper as we move further to the south, while very deep sands (over six feet deep) occur near Happy Valley Reservoir. It appears that the sand of the A horizon has gradually drifted down the fault block, stripping the profile in the north and accumulating in the south. Of course, much of the sand will be washed away down the valleys, and there is a possibility that the sands were winnowed during the arid period proposed by Crocker (8). Also there may have been a supplement of sand from the higher fault blocks. Hence, consequent to these movements, the results of mechanical analysis (see Appendix I) show that the coarse sand : fine sand ratios of the sand and the clay horizons do not agree as found by Northcote for a residual laterite on Kangaroo Island (12). Similarly on the Ochre Cove Fault Block, the truncated laterite is seen at Cherry Gardens, while further to the south a sandy A horizon, which becomes progressively deeper, occurs. Near Blewett's Springs and McLaren Flat, to the south of the area surveyed, deep lateritic sand accumulations occur. On this fault block the laterite extends for at least 30 miles to the south. On the Willunga Fault Block only truncated laterite has been observed as yet. This truncated laterite has been called Kuitpo gravelly sandy loam by Taylor and O'Donnell (21).

The Bradbury kaolin mine is indicative of truncation of the deep lateritic profile to the pallid clay horizon. In recent times up to 12 inches of grey clayey soil of poor nutrient status has developed over the kaolin.

For convenience the lateritized soils will be divided into four classes, the general profile characteristics of which are illustrated in fig. 6.

1. *Residual lateritic podsols*

This soil is characterised by a coarse sandy surface which may vary from 8 to 27 inches in depth and which contains about 50% of ironstone gravel in the lower six inches. Quartz gravel often occurs with the ironstone. Owing to accumulations of organic matter near the surface the upper few inches are usually dark grey in colour, while the remainder of the sandy horizons are light grey to

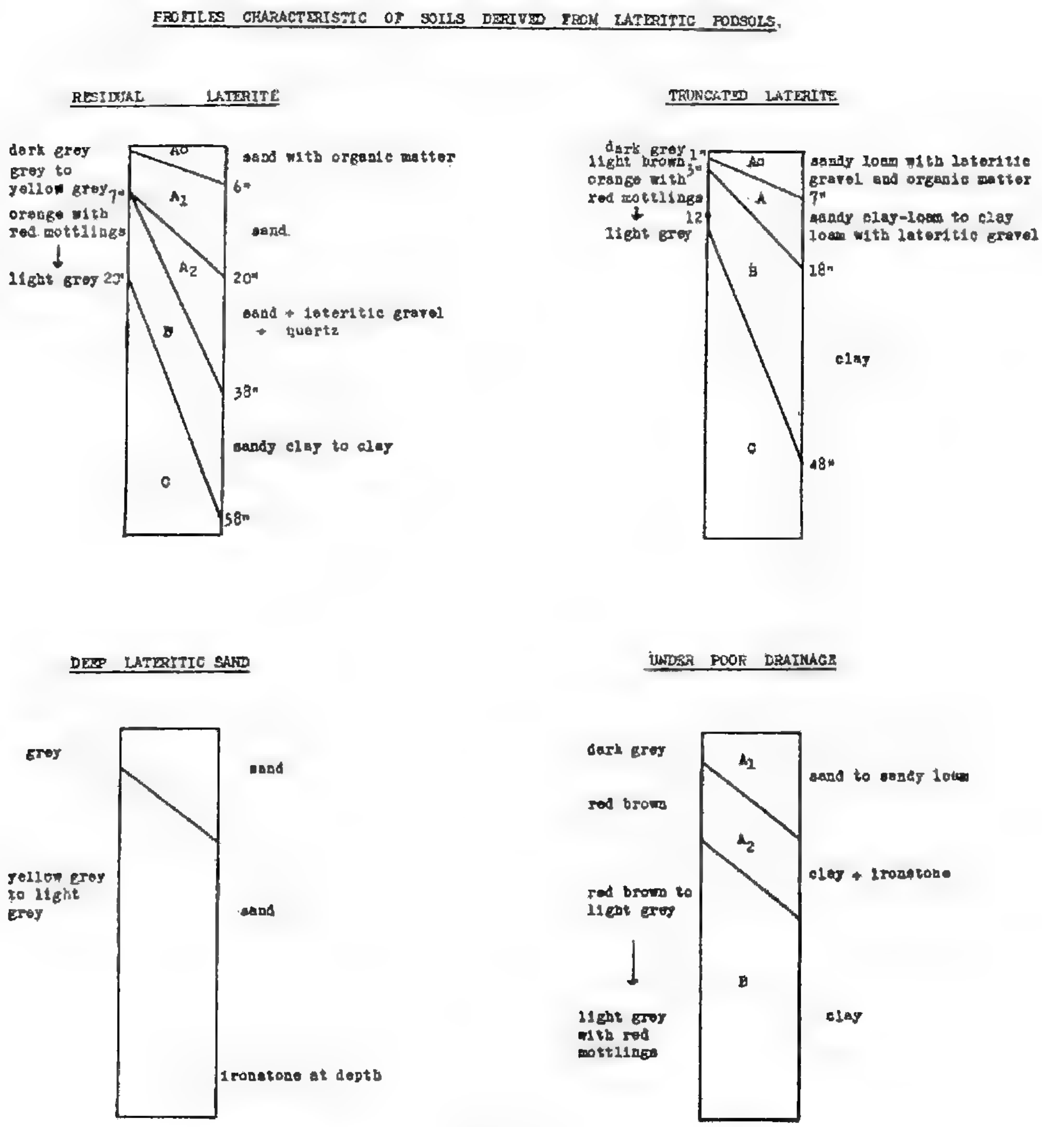


Fig. 6
Soil profiles characteristic of soils derived from lateritic podsols.

yellow-grey. Underlying the sandy surface horizon there is a mottled yellow-brown, yellow-grey and light grey clay which may contain some ironstone gravel in the upper few inches. The light grey colour usually increases with depth.

Mechanical analyses show great variation in the coarse sand : fine sand ratio, possibly because of the movements of the A horizons as mentioned above. The results of the chemical analyses show the soils to be extremely poor in P_2O_5 and nitrogen. Much of the organic matter is in a fibrous condition and does not break down readily to available forms of nitrogen. Throughout the profile the soil is acid in reaction (see Appendix I).

2. *Truncated lateritic podsols*

These soils are similar in formation to the previous one, but there is little of the sandy A horizon present. The ironstone may be in large boulders or broken down to pisolitic gravel.

The profile consists of a brown to grey loamy surface overlying at a depth of 1 to 7 inches a yellow-brown to red-brown clay containing red mottlings. There are often large pieces of ironstone 6 to 12 inches in diameter near the surface of the soil. At about 12 inches the clay becomes mottled red-brown, yellow-brown and light-grey. The light grey colour increases with depth until, below about 2 or 3 feet, it is by far the dominant colour with only a few red-brown inclusions in it.

The results of chemical analysis show that these soils are slightly higher in nutrient status than the residual lateritic podsol. The nitrogen figure is not a true index of the available nitrogen, as most of it is present as undecomposed organic matter (see Appendix I).

3. *Deep lateritic sands of acid reaction*

Within the area of residual lateritic podsols there are several areas of deep sands containing ironstone at depth. The profile consists of a grey sand overlying a yellow-grey to light grey sand at variable depth. Near Blewett's Springs these sands are predominantly coarse, the ratio of coarse sand to fine sand being 8 or 10 to 1. The silt and clay fraction is never higher than 3-5% in the first 36 inches. The high coarse sand : fine sand ratio suggests that these sands may have been winnowed by the winds of the arid period (8). The mechanical composition is remarkably constant with depth.

These soils are the most acidic (pH 5·0-5·5) and the poorest in nutrients of all the soils in the area (see Appendix I).

4. *Lateritic podsols under swampy conditions*

In several small isolated positions within the range of distribution of the residual lateritic podsol these soils occur in flat and relatively low-lying situations. Under these circumstances they become waterlogged in winter, due to the impervious nature of the underlying clay. The profile is similar to the residual laterite podsols.

B. Soils formed under present environmental conditions

Where complete truncation of the lateritic profile has occurred, soils have developed on the underlying rock in recent times. These soils show a close correlation with the parent material, podsols being developed over siliceous rocks, grey-brown podsols and red-brown earths over argillaceous rocks, calcimorphic soils over calcareous rocks, and ferrimorphic soils over gneissic and schistose rocks. Climate has been responsible for the differentiation of some of the soil groups. The red-brown earth grades into the grey-brown podsol at the 25-inch isohyet, and this in turn is progressively more leached with the increase in influential rainfall until the nutrient status is so low that a definite sclerophyllous formation takes the place of the savannah formation about the 35-inch isohyet. In areas of impeded drainage deep degraded rendzinas occur. These grade into shallow rendzinas in drier conditions.

Products of denudation tend to accumulate in some valleys forming a valley complex, while a saline alluvial flat has formed near the mouth of the River Onkaparinga.

1. *Podsols*

Wherever siliceous rocks of low cation status, such as quartzites and sandstones, are exposed, podsols develop. As these rocks are very resistant to weathering, most of the area over which they occur is very rugged and bold in outline and skeletal podsols are developed (see fig. 7). However, in regions of rainfall greater than 35 inches per annum and on the tops of ridges the moisture

has been sufficient to severely leach the weathered material of such low cation status, and to produce a mature podsolic profile. Typically, the mature podsol shows a sandy A horizon containing floaters overlying a B horizon of sandy clay to clay (see fig. 7). On analysis these soils were seen to be low in P_2O_5 and total nitrogen and acid in reaction (see Appendix I).

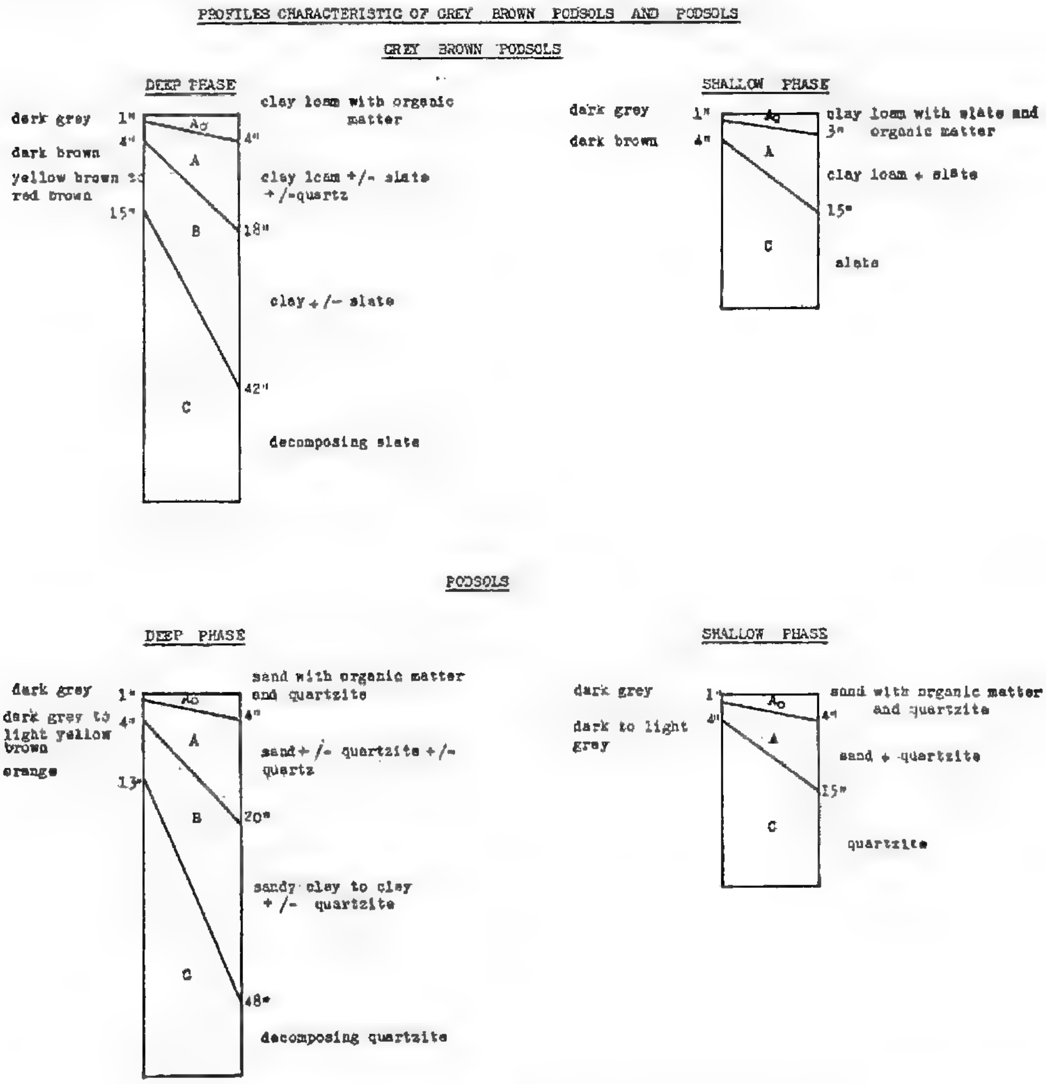


Fig. 7
Soil profiles characteristic of grey-brown podsols and podsols.

However, small areas of quartzites in the Middle and Upper Adelaide Series tend to give skeletal podsols of a slightly higher nutrient status than siliceous rocks of the Lower Adelaide Series (see Appendix I), but these outcrops are apparently ecologically insignificant in their effect on the distribution of the tree stratum.

2. *Grey-brown podsols*

In that section of the area with rainfall greater than 25 inches per annum, argillaceous rocks, such as slates, phyllites and Sturtian tillite have given rise to a profile typical of a grey-brown podsol. In the mature phase this soil shows an A horizon of a clay-loam sometimes containing floaters over a clayey B horizon

(see fig. 7). This mature profile is developed more extensively than in the case of a podsol (see above) because of the faster rate of weathering of the argillaceous rocks, but it is seen especially in wetter regions (rainfall greater than 30 inches per annum) and on the tops of ridges. In drier regions between 25 and 30 inches per annum weathering is probably not so rapid, as erosion is nearer equilibrium with decomposition and only an immature form of the soil is developed (see fig. 7).

Analyses show that in the drier extent of the grey-brown podsols the soil is relatively higher in P_2O_5 and total nitrogen but grades into a soil about three times lower in P_2O_5 and total nitrogen approximately along the 35-inch isohyet (see Appendix 1).

It appears that this decrease in nutrients is caused by increased leaching with increased rainfall. This is supported by the fact that the savannah formation on the relatively high nutrient status grades imperceptibly into sclerophyllous formation on the relatively low nutrient grey-brown podsols with increase in rainfall. In all cases the profile is acidic. However, the low nutrient grey-brown podsol is from three to four times higher in nutrient status than the podsol.

As would be expected in sedimentary rocks, variations occur within the slate, some tending to be more siliceous in composition than others. These slates consequently give rise to a profile sandier than that described above.

3. *Calcimorphic soils*

The main area on which these soils are developed lies between the coast and the Ochre Cove Fault scarp. Thick beds of Miocene marine limestone occur in the southern half of this fault block, while cappings of travertine limestone have overlain the Adelaide Series in the northern half, and Miocene limestone in the southern half of the fault block. On these limestones and other limestone outcrops of the Adelaide Series alkaline calcimorphic soils have developed.

The travertine limestone probably had a loessal origin during the arid Pleistocene to Recent Periods as proposed by Crocker (8). With faulting in the Pliocene to Pleistocene, dissection of the original peneplain would occur, producing valleys and completely eroding most of the lateritic profile formed in the Pliocene. Later in the arid period loessal matter would be deposited over the soil of the whole area and leached to varying degrees, depending on the influential rainfall pattern. We can assume that, in the Adelaide Hills, the pattern of annual rainfall must have been much the same as at present (see fig. 1), but of course lower in amount.

Consequently the calcium carbonate was entirely leached out in the higher rainfall regions, either then or under the present climate. However, in the more arid region—now indicated by a rainfall less than 25 inches per annum—the calcareous matter was leached down to the underlying rock and there deposited as travertine. This travertine would be formed over the whole topography but subsequent erosion, especially in the present moister climate, has worn it away greatly on the slopes and completely in the valleys where the underlying rock is exposed. Of course, it cannot be dismissed that the calcareous slates and quartzite might have added to the travertine, but it is too widespread over non-calcareous rocks, especially near Tapley's Hill, for this to account entirely for its origin. One would expect to find travertine overlying laterite in some places. But, as yet, the only indications are the presence of ironstone within the travertine on Shepherd's Hill and around the degraded rendzina on O'Halloran Hill (Sprigg 17). This laterite may be detrital lumps from higher altitudes. Stephens has also noticed a buried lateritic profile about a mile north of Christie's Beach (private communication).

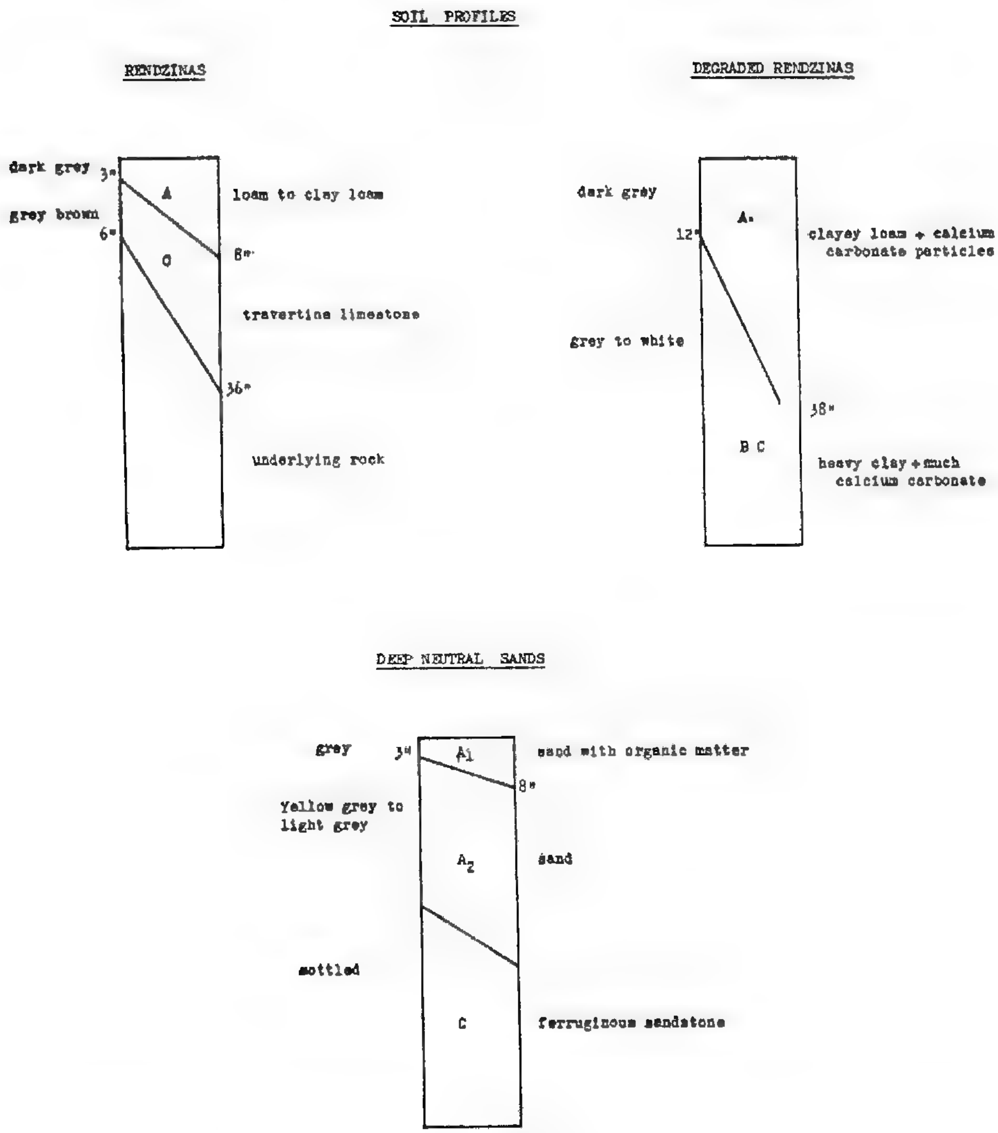


Fig. 8

Soil profiles characteristic of rendzinas, degraded rendzinas and deep neutral sands.

Over most of the travertine a dark greyish-brown loam has developed which shows very little differentiation into horizons. The depth of the soil may vary from 3 to 15 inches, but in many places the travertine is visible above the surface (fig. 8). The soils are well supplied with organic matter and have a fairly high nutrient status. These soils—rendzinas— have been cleared of vegetation and the land used extensively for cereal growing and vineyards.

Interspersed with the rendzinas near Reynella are small areas of red soil of lighter texture, which resemble terra rossas. Soils allied to terra rossas have developed on the Torrens and Beaumont limestone outcrops in the northern half of the area, where they grade into the acid grey-brown podsols.

Under conditions of retarded drainage the limestone has undergone extreme decomposition, producing a deep degraded rendzina of heavy texture (fig. 8). There is a narrow fringe of these deep black soils at the boundary between the shallow rendzina soils and the grey-brown podsols.

Along the Eden Fault scarp these calcimorphic soils grade into the red-brown earths of the Adelaide Plains, while to the east of their extent they grade into soils allied to red-brown earths developed over slates.

4. *Red-brown earths*

This soil is developed on the Adelaide Plains where the rainfall is less than 25 inches per annum, and appears to grade imperceptibly into grey-brown podsols along the Eden Fault scarp and into the calcimorphic soils in the south-west corner of the Plain. As no survey or analyses have been made over this area, the reader is referred to Piper (13) who gives a detailed description and analysis of the profile developed at the Waite Institute (the Belalie loam). In general the soil is relatively high in P_2O_5 and nitrogen and becomes alkaline in the B horizon, due to accumulation of calcium carbonate.

It is possible that the calcium carbonate in the profile is of the same loessal origin as that proposed by Crocker to explain the origin of the mallee soils (8), the loess being deposited over the deep detrital soils of the Plain during the arid Pleistocene to Recent Periods and subsequently leached, especially in the moister present climate, to form the red-brown earth profile. The degree of leaching, especially of the calcium carbonate, depends to a large extent on the rainfall, for at about the 25-inch isohyet there is a transition to allied grey-brown podsols which have no trace of calcium carbonate in the profile.

5. *Ferrimorphic soils* (?)

As these soils are of limited extent to the east of Mount Lofty Summit and along the Torrens Gorge, little data is available. They are developed on schistose and gneissic rocks of the Barossian Complex and appear to be lacking in profile development. Superficially they are similar to the shallow form of the grey-brown podsol and in some cases are indistinguishable from it. From the sclerophyllous nature of the undershrubs, they are apparently low in nutrient status. As large areas of these soils occur to the north of the Torrens Gorge a more complete examination of these soils will be made by one of us in a subsequent paper.

6. *Deep sands with neutral reaction*

These soils are of limited occurrence and occur mainly near Noarlunga and Hackham. The soil consists of a grey surface horizon containing some organic matter overlying a yellow-red or a yellow-grey sand at 3 to 8 inches. The underlying C horizon is a mottled light grey, yellow and red ferruginous sandstone (see fig. 8). The soil is slightly alkaline throughout and has a poor nutrient status. The coarse sand figure is very high, which suggests that the sand from which the underlying sandstone was formed had been winnowed.

7. *Miscellaneous soils*

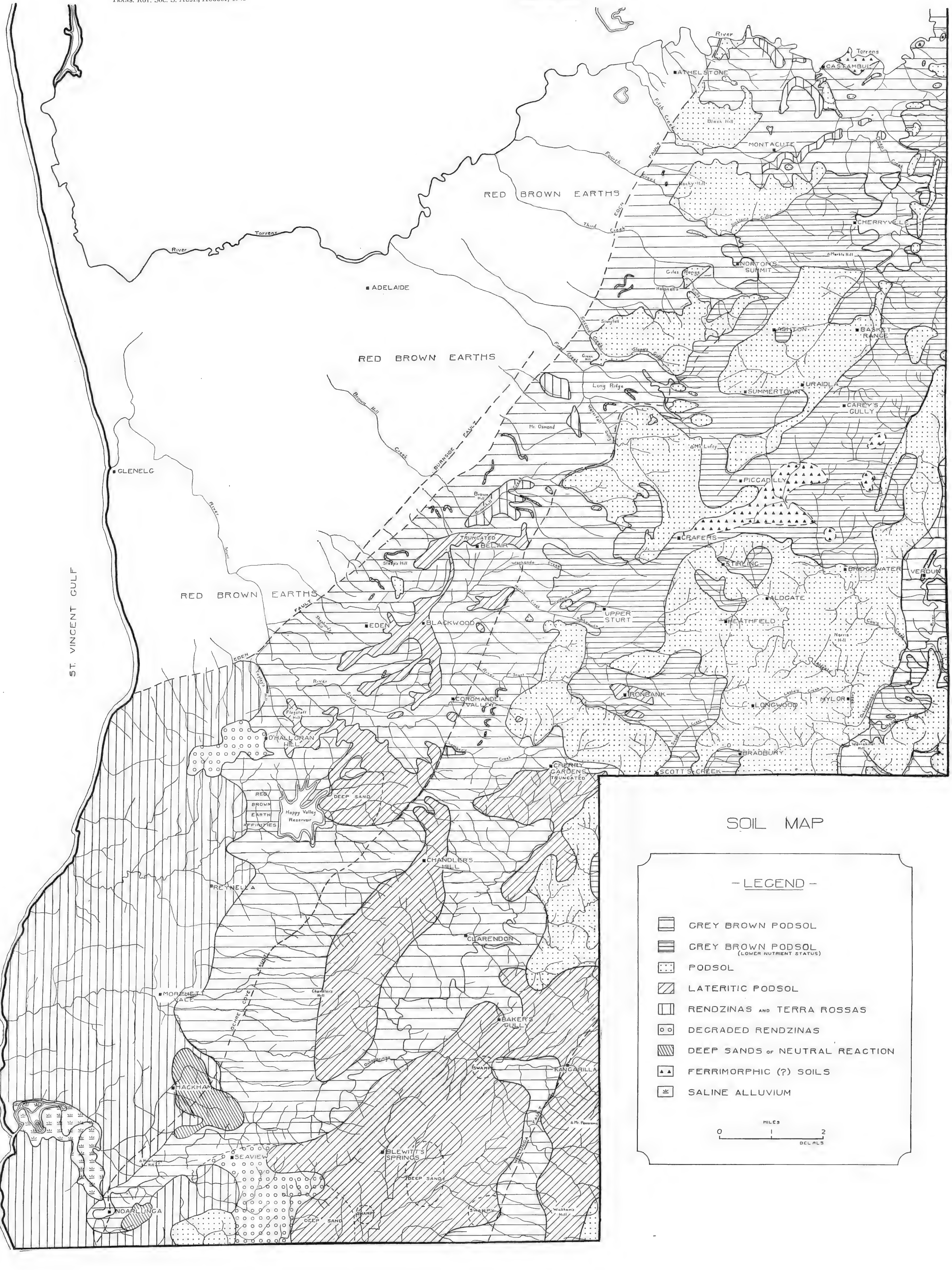
Several other soils in addition to those described above occur only in small areas.

(1) Along the drainage lines which have cut into the Willunga Fault Scarp near Kangarilla there is a soil which is waterlogged throughout the year. The profile consists of two inches of grey sand containing organic matter overlying a light grey clay, which is particularly heavy and sticky. A sclerophyllous formation dominated by *E. leucoxylon* is developed over this soil (see Appendix I).

(2) Near Seaview a red sandy soil occurs. 18 inches of red coarse sand overlies red clay, which becomes heavier and yellower at 24 inches (see Appendix I).

TABLE I

Formation	Community	Common Name	Rainfall Range	Soil	Remarks
Savannah woodland	*E. odorata* association	Peppermint gum	20 – 30" p.a.	Calcimorphic soils, red-brown earths, podsols, grey-brown podsols, laterites	Controlled only by water relations within soil. North-facing aspects near 30" isohyet; extensive below 25"
Savannah woodland	*E. leucoxylon-E. viminalis* association				
	1. *E. leucoxylon* type	Blue gum	25 – 40" p.a.	Truncated laterites and grey-brown podsols	Controlled by water relations and soils of high nutrient status. (a) North-facing aspects > 30" South-facing aspects < 30" (b) South-facing aspects and valleys in wetter parts.
	2. *E. viminalis* type	Manna gum	30 – 40" p.a.		
Savannah woodland	*E. camaldulensis* association	Red gum	20 – 35" p.a.	Grey-brown podsols and alluvial soils	Fringes watercourses below 27"; extends above 27".
Sclerophyll scrub	*Casuarina stricta* association	Sheoak	20 – 35" p.a.	Deep siliceous sand of neutral reaction or steep skeletal slopes	Very low water requirements
	Stringybark edaphic complex				
Sclerophyll woodland	1. *E. fasciculosa* association	Pink gum	22 – 30" p.a.	Medium to low nutrient status Podsols and laterites especially deeper residual laterites	Low water requirements. Rare trees of *E. leucoxylon*
Sclerophyll Scrub to woodland	2. *E. Baxteri-E. cosmophylla* association	Brown stringy-bark-scrub gum	35 – 40" p.a.	Podsols and laterites	Sunny aspects of ridges
Sclerophyll forest	3. *E. Baxteri-E. obliqua* association	Stringybarks	35 – 48" p.a.	Podsols and laterites	On drier positions within this rainfall range
Sclerophyll forest	4. *E. obliqua* association	Stringybark	35 – 48" p.a.	Highly leached grey-brown podsols	On soil of better nutrient status and water relations than *E. obliqua-E. Baxteri* associations
Sclerophyll forest	5. *E. rubida* association	Candlebark gum	35 – 48" p.a.	Highly leached grey-brown podsols and alluvial soils	Watercourses from 35 – 45"; extends above 45".
	6. Types and ecotones between these associations				
Sclerophyll and savannah woodlands	*E. odorata-E. leucoxylon-E. fasciculosa* ecotone 1. *E. odorata-E. leucoxylon* sclerophyll 2. *E. odorata* sclerophyll 3. *E. leucoxylon* sclerophyll 4. *E. viminalis* sclerophyll 5. *E. odorata-E. leucoxylon* savannah		25 – 30" p.a.	Sclerophyll woodland on laterite Savannah woodland on grey-brown podsol	Ecotone between *E. odorata* association, *E. leucoxylon-E. viminalis* association and *E. fasciculosa* association


SOIL MAP
- LEGEND -
GREY BROWN PODSOL
GREY BROWN PODSOL (LOWER NUTRIENT STATUS)
PODSOL
LATERITIC PODSOL
RENDZINAS AND TERRA ROSSAS
DEGRADED RENDZINAS
DEEP SANDS OF NEUTRAL REACTION
FERRIMORPHIC (?) SOILS
SALINE ALLUVIUM
MILES
0 1 2
RED BROWN EARTHS
RED BROWN EARTHS
RED BROWN EARTHS
ST. VINCENT GULF
ADELAIDE
GLENELG
ATHELSTONE
CASTAMBUL
MONTACUTE
CHERRYVILLE
NORTON'S SUMMIT
ASHTON
BASKET RANGE
URAIDLA
SUMMERTOWN
CAREY'S GULLY
PICCADILLY
CRAFERS
STIRLING
BRIDGEWATER
VERDUN
ALDGATE
HEATHFIELD
UPPER STURT
BELAIR
EDEN
BLACKWOOD
IRONBANK
LONGWOOD
MYLOR
CORAMANDEL VALLEY
O'HALLORAN HILL
BRADBURY
SCOTT'S CREEK
CHERRY GARDENS
Happy Valley Reservoir
RED BROWN EARTH AFFINITIES
DEEP SAND
CHANDLER'S HILL
REYNELLA
CLARENDON
MORPHETT VALE
BAKER'S GULLY
KANGARILLA
HACKHAM
SEAVIEW
BLEWITT'S SPRINGS
NOARLUNGA
EDEN FAULT
BURNSIDE FAULT
OCHRE COVE FAULT
River Torrens
Mt. Lofty

(3) Saline alluvial flats have been developed near the mouth of the Onkaparinga River. These consist mainly of variable Recent alluvium containing shells. Parts are subject to flooding on exceptionally high tides, as there is no part of the flats higher than 10 feet above sea level.

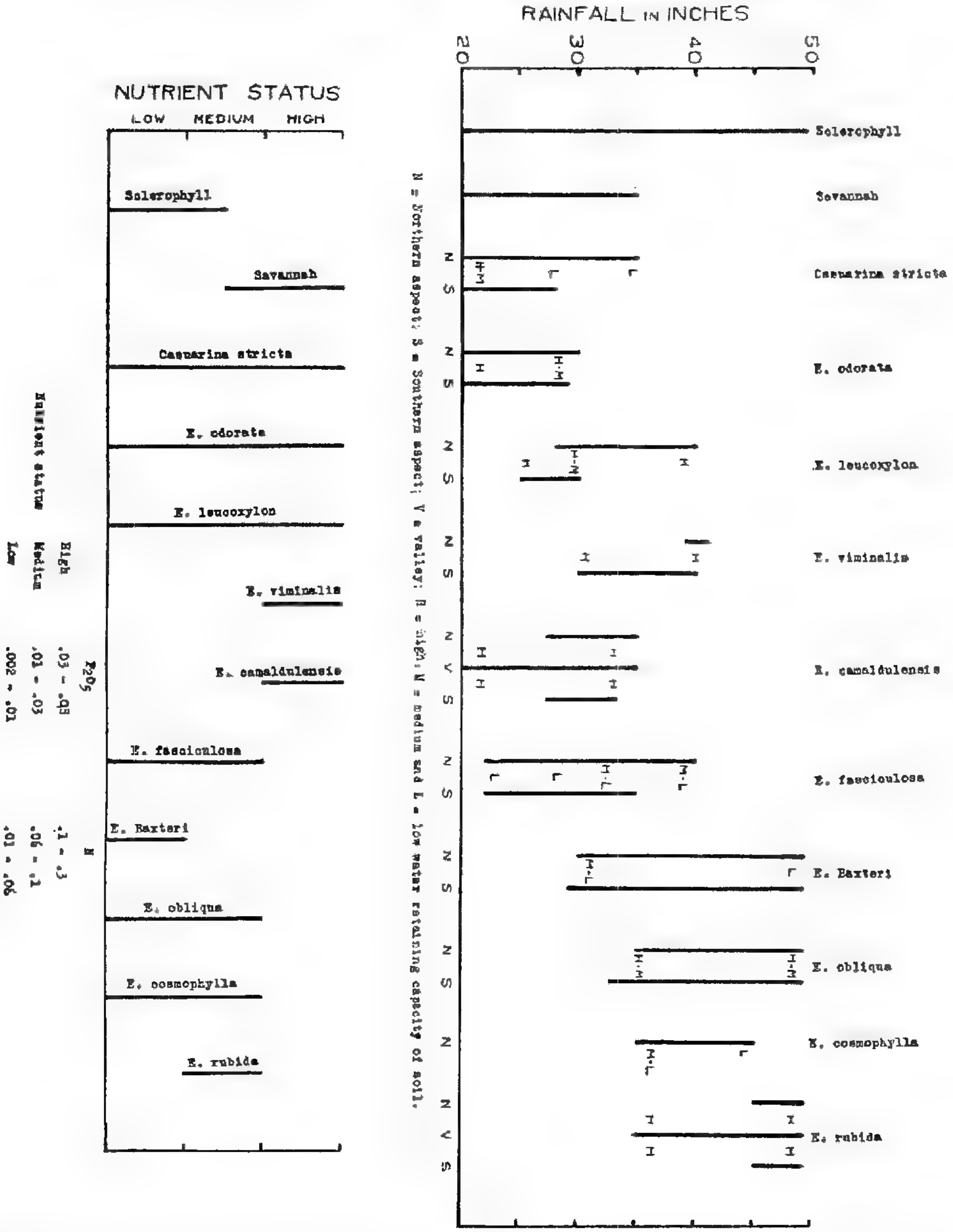


Fig. 9

Diagram showing the relationship of the dominant Eucalypt species with rainfall and nutrient status of the soils.

THE VEGETATION

It was found on reconnaissance that numerous changes in the species composition of the vegetation occur over a very small area. Consequently it was

deemed advisable that the autecology of individual species should be investigated. A summary of the results obtained is shown in fig. 9, 10 and 11. Following the discussion on the environmental range of the species, there is an endeavour to group the species into logical communities, but of course any attempt is largely artificial and only for convenience. The nomenclature of the species follows that of Black (3) and Blakely (4).

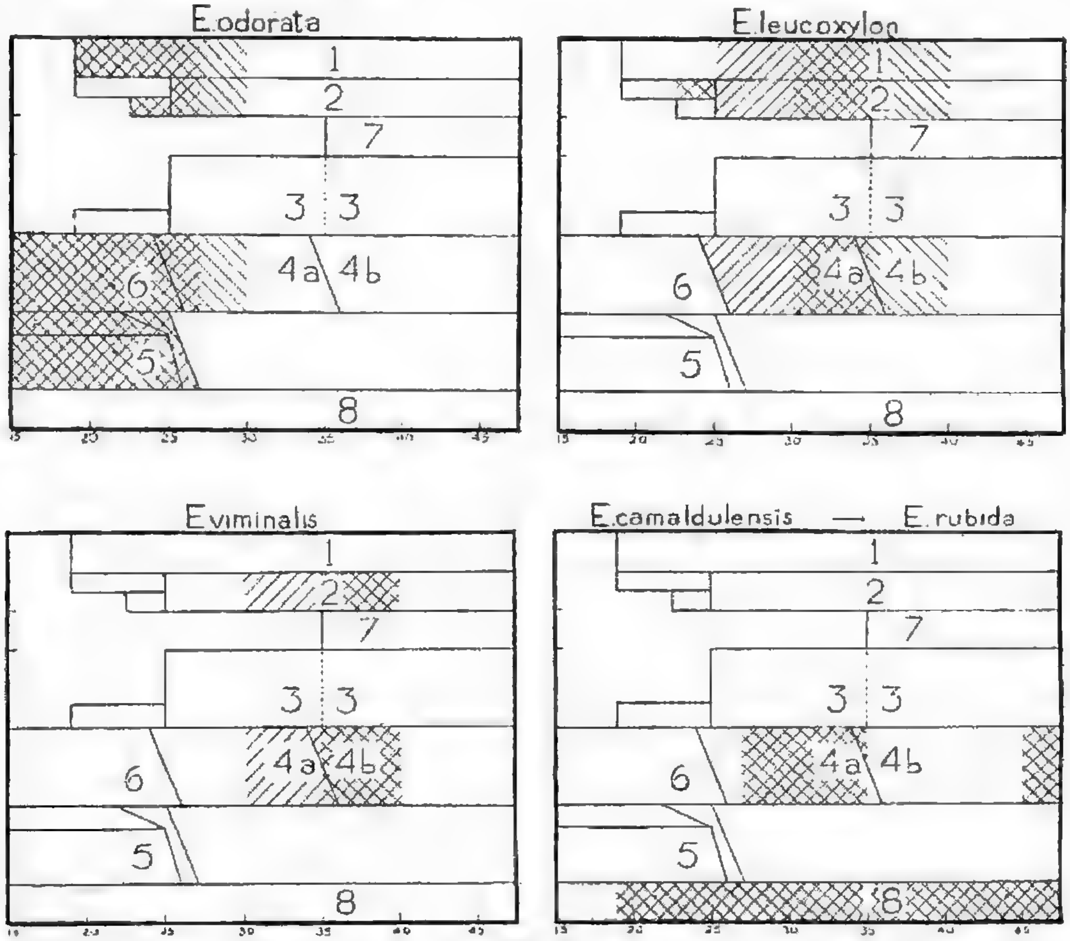


Fig 10

Diagram illustrating the distribution of various species of *Eucalyptus* in relation to soils and rainfall. The numbers on the figures refer to soils named in Figure 5.
Hatching from right to left (downwards) indicates presence on South-facing aspects only.
Hatching from left to right (downwards) indicates presence on North-facing aspects only.
Cross-hatching indicates presence on both aspects.

A. Environmental Range

1A. *Eucalyptus odorata* (peppermint gum)

This species warrants further investigation in regard to its acceptance as a genotype, for, especially in its eastern limit, the peppermint gums exhibit a large variation in characteristic features. R. G. Brett (private communication) suggests that the species is actually a hybrid polymorph between *Eucalyptus odorata, Eucalyptus fasciculosa,* and possibly a mallee with *E. odorata* the dominant member of the cross. However as all peppermint gums, which show the same wide range in morphology, agree with Blakely's broad description of *E. odorata,* his description is accepted in this report.

E. odorata occurs within the drier part of the area, the 30-inch isohyet forming approximately the upper limit of the species, while the coast forms a barrier to it reaching the lower limit of its potential range. The species appears to be uninfluenced by the texture, the pH, or the nutrient status of the soil, for it

flourishes equally well on red-brown earths, grey-brown podsols, podsols, residual and truncated laterites, and over the calcimorphic soils which occur within this rainfall range. It has been noted that towards the wetter limit of its distribution there is a marked tendency for the species to occur on the drier northern aspect only. Towards its drier limit the species is confined to soils of relatively high water-retaining capacity such as calcimorphic soils and red-brown earths, but as the rainfall increases, the species can spread over truncated laterites or residual laterites with a shallow A horizon, both of which though low in nutrient status have a clay horizon near the surface. However, the peppermint gums never occur on the deeper lateritic sands nor on the skeletal podsols developed over the thick quartzite of the Adelaide Series. These soils have a relatively low water-retaining capacity. These facts indicate that it is the moisture relations within the soil which are the major controlling factors in its distribution. This is illustrated in fig. 10.

The potential range of the species in this area is far wider than that found in other parts of the State, for Crocker (7), Jessup (11) and Piper (13) have shown that the species is restricted, in the areas which they studied, to red-brown earths (sometimes becoming slightly podsolised) within rainfall limits of 15 to 25 inches per annum. On Eyre Peninsula (7), where the maximum rainfall is only 24 inches per annum, the species is restricted to the red-brown earths between 18 and 20 inches per annum, although podsols and residual podsols occur contiguous to it.

Jessup (11) also deals with the drier limits (15 inches per annum) of the distribution of *E. odorata* on the eastern side of the Mount Lofty Ranges. Around Bordertown, in the Upper South-East, the species flourishes on calcimorphic soils with a rainfall of 20 inches per annum. Hence it appears that in the drier limit of its range *E. odorata* is mainly confined to alkaline soils of clayey nature, which have a high water-retaining capacity, whereas a wider range in regard to soils occurs towards its wetter limit, provided the higher rainfall and the lower water-retaining capacity of these soils compensate to satisfy the water requirements of the developing *E. odorata.*

1B. "Whipstick peppermint" ecotype of *Eucalyptus odorata*

At the foot of Black Hill on a podsol developed over the Mount Lofty quartzite, two distinct areas of this "whipstick mallee" occur within the *E. fasciculosa* sclerophyll community. The tree appears to approach Blakely's description of *E. odorata* var. *angustifolia,* although many of the trees exhibit fruits of the same size as the typical *E. odorata.*

As this ecotype of *E. odorata* is of restricted occurrence it can only be noted that the soil is a podsol, low in nutrient status, and developed with a rainfall of approximately 25 inches per annum.

2. *Eucalyptus leucoxylon* (blue gum)

This species is largely controlled in its distribution by the moisture relations within the soil. It occurs within the limits of the 25-inch and 40-inch rainfall isohyets, but within this range it is markedly influenced by aspect. In the drier limits the species occurs either mixed with *E. odorata* or alone on the shady, moister, south-facing slope, but as the rainfall increases to about 30 inches per annum it occupies both slopes, while with further increase the species is confined to the warmer, drier, north-facing slope of the ridges. This phenomenon is masked in the northern half of the area where the rainfall increases rapidly along the scarp from 25 inches to 30 inches per annum within three-quarters of a mile,

thus limiting *E. leucoxylon* to the north-facing slopes, whereas in the south the same increase occurs gradually over two miles. Within this range occur grey-brown podsols with relatively high nutrient status, and residual and truncated laterites of relatively low nutrient status. However, although these soils differ in nutrient status, their water-retaining capacities, apart from the shallow sandy horizon of the residual laterite, would be of the same order. The fact that water relations play a large part in controlling the species distribution is further substantiated by the appearance of *E. leucoxylon* on residual laterites in the fringing community around the deeper lateritic sands in the southern part of the area. Here *E. fasciculosa* is distributed over the deep sands of the ridges with *E. leucoxylon* occupying an area, often only a few chains wide, on the shallower sands of the residual laterite, the clay horizon of which would tend to produce better water relations within the soil. In the wetter situations of the drainage lines and adjacent flat areas, *E. camaldulensis* takes the place of *E. leucoxylon*. *E. camaldulensis* also tends to supplant *E. leucoxylon* over the grey-brown podsols on wetter ridges along the Torrens Gorge, the Sturt River, and the River Onkaparinga. However, two exceptions to this general scheme occur.

The podsols developed on the Mount Lofty quartzite act as a barrier to the distribution of the species. Wherever podsols occur, in whatever rainfall, there is a sharp division between the blue gums on the grey-brown podsols and the "stringybark complex" on the podsols. This is rather curious, for the podsols and laterites are of approximately the same acidity and nutrient status in P_2O_5 and nitrogen. Of course, most of the podsols are of a very skeletal nature, especially in their drier limit, and possess a low water-retaining capacity. This fact may be of value, but there is no gradual transition evident from blue gum to the "stringybark complex" as there is with increase in rainfall and decrease in P_2O_5 and nitrogen with leaching on the grey-brown podsols. This data suggests that some other factor is influencing its distribution as well as moisture relationships. It may be micro-nutrient deficiency on the podsols. It may be bound up with competition between the trees of the "stringy-bark complex" and the "blue gums."

There is also a small occurrence of blue gums on deep lateritic sands near Happy Valley Reservoir which seems an exception to the general scheme of water relations. Fig. 10 shows the general relationship existing between *E. leucoxylon*, soils, and rainfall. In other parts of the State water relations seem to be a prominent controlling factor. On the eastern side of the Mount Lofty Range Jessup (11) has found blue gums occurring on red-brown earths with a rainfall as low as 15 inches per annum. It should be noted that these soils would possess a relatively high water-retaining capacity. Boomsma (5), working on the Southern Flinders Ranges, also gives evidence which indicates that water relations play a large part in the species' potential environment. He found blue gums along the watercourses where the annual rainfall was over 16 inches, on red-brown earths with an annual rainfall greater than 17 inches, and on podsols of lower water-retaining capacity with an annual rainfall greater than 21 inches for savannah and greater than 26 inches for sclerophyll formations associated with it.

3. *Eucalyptus viminalis* (manna gum)

This species occupies the moister, south-facing aspect of the ridges with *E. leucoxylon* or *E. camaldulensis* occupying the northern aspect between the 30- and 40-inch isohyets (see above). In higher rainfall areas it tends to occur along watercourses. The density of the trees increases with rainfall from an open woodland on the drier side to a closed forest in its wetter limit. Although this species occurs in small areas on truncated lateritic soils it is largely confined to

the richer grey-brown podsols. This is probably due to higher water relationships within the grey-brown podsols. The distribution of *E. viminalis* in relation to soils and rainfall is shown in fig. 10.

4. *Eucalyptus camaldulensis* (syn. *E. rostrata*) (river red gum)

In the drier limit of the area this species is confined to the creek beds or to some distance on each side, but along the Rivers Torrens, Sturt and Onkaparinga, where the annual rainfall is greater than 27 inches, it extends over larger areas. The species is confined to grey-brown podsols on the slopes and ridges and alluvial soils in the valleys, both soils being rich in P_2O_5 and nitrogen and having high water relations. Where the redgums extend over the ridges near the rivers they tend to occupy a similar habitat to that of *E. leucoxylon* on ridges alongside minor streams. The species does not extend into areas with rainfall greater than 35 inches per annum. Its soil and rainfall requirements are summarised in fig. 10.

5. *Eucalyptus obliqua* (stringybark)

This species is a dwarf ecotype of the species growing in the eastern States, for it rarely grows higher than 80 feet.

This stringybark occurs on a wide variety of soils, such as podsols, highly leached grey-brown podsols, lateritic soils, and ferrimorphic soils (all of which are low in P_2O_5 and nitrogen), provided the annual rainfall is greater than

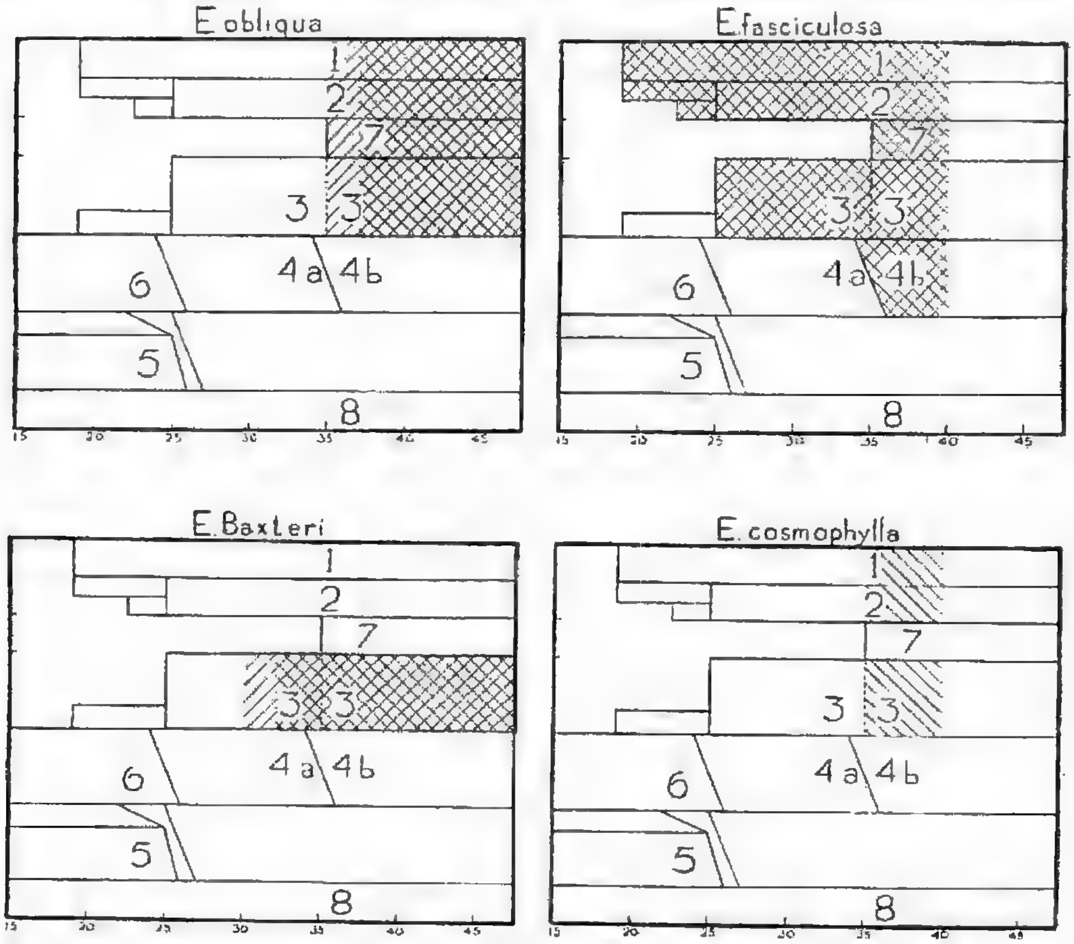


Fig. 11

Diagram illustrating the distribution of various species of *Eucalyptus* in relation to soils and rainfall. The numbers on the figures refer to soils named in Figure 5.
Hatching from right to left (downwards) indicates presence on South-facing aspects only.
Hatching from left to right (downwards) indicates presence on North-facing aspects only.
Cross hatching indicates presence on all aspects.

approximately 35 inches. It extends up to the maximum rainfall for the area of 48 inches per annum on Mount Lofty Summit. Aspect plays a part in its distribution towards its drier limit, for it tends to occupy the moister southern aspect On the grey-brown podsols it tends to form either a pure community or one mixed with *E. viminalis* on the southern aspect, while a pure community of *E. leucoxylon* occurs on the northern aspect.. Similarly towards the drier limit of *E. obliqua* on the podsols, *E. obliqua* tends to occur with *E. Baxteri* on the southern aspect, while *E. Baxteri* and *E. fasciculosa* occur on the northern. The soil and rainfall requirements of *E. obliqua* are illustrated in fig. 11.

If we remember that a large percentage of the rainfall is lost to the soil by run-off in the Adelaide Hills, the environmental ranges found by Crocker on the low undulating sand-dunes of the South-East (6), and by Baldwin and Crocker on the flat lateritic peneplain of Kangaroo Island (2) are comparable to that shown above for the Adelaide Hills. It should be noted here that on the flatter country of the other two localities the lower rainfall limit of the species may be as low as 24 inches per annum.

6. *Eucalyptus Baxteri* (brown stringybark)

This species has a restricted range of soil nutrients, occurring on only the very poor podsols, but with a wider moisture range than that of *E. obliqua* (see fig. 11). This is especially evident where the podsols developed over the thick quartzite of the Adelaide Series occur in regions with rainfall as low as 30 inches per annum such as on Black Hill, Morialta and Stonyfell Ridge. In these localities *E. Baxteri* tends to occur with *E. fasciculosa* on the moister south-facing side of the ridge towards its drier limit, while *E. fasciculosa* occupies the northern aspect alone. However, with increase in rainfall *E. Baxteri* soon occupies both aspects, while *E. obliqua* occurs with it at first on only the southern aspect but eventually at about the 35-inch isohyet on both aspects. As the rainfall increases still further *E. Baxteri* tends to be more prevalent on the skeletal quartzites than *E. obliqua*, and where the podsols are better developed there is a tendency for *E. Baxteri* to occur on only the drier aspects.

However, although the environment appears to be suited for its growth, no specimen of *E. Baxteri* was found on the podsol on Acklands Hill. Taylor and O'Donnell (21) have noted *E. Baxteri* occurring on truncated laterite in the Hundred of Kuitpo, and the authors have noted similar occurrences further down the Fleurieu Peninsula. Considering these occurrences, it at first seems rather surprising that *E. Baxteri* is not found on the lateritic soils of the area, but on closer examination it is seen that these soils are mainly in regions with annual rainfall less than 35 inches, and this wetter limit is near the apparently anomalous area on Ackland's Hill.

Taking into consideration the effect of differences of topography on moisture relations within the soil between the Adelaide Hills, Kangaroo Island (lower rainfall limit approximately 20 inches per annum) and the South-East (lower limit about 22 inches per annum), the environmental range of *E. Baxteri* is similar in the three habitats, that is, the species is restricted to soils very low in P_2O_5 and nitrogen such as podsols and laterites, and with a lower range of moisture relations than *E. obliqua*.

E. *Eucalyptus fasciculosa* (pink gum)

This species occupies the driest position in the "stringybark complex", occurring in areas with rainfoll as low as 22 inches per annum and extending up to 40 inches per annum. In all the localities where this species has been found the soil is acidic and low in P_2O_5 and nitrogen, but the texture of the soils (all

phases of laterite podsols, highly leached grey-brown podsols and ferrimorphic soils), varies considerably.

In its drier limit the species is confined to podsols and residual laterites with a deep sandy A horizon or deep lateritic sands, the species maintaining its position only by the fact that these soils have a very low water-retaining capacity. When the A horizon becomes shallower, the water relations of the soil for the same climate improve, and *E. fasciculosa* gives way to *E. leucoxylon*. As most of the country where it occurs is gently undulating, aspect here plays little part.

In the drier limit of its distribution on the podsol of Black Hill, Rocky Hill and Stonyfell Ridge the species occurs pure on steep, skeletal, quartzite slopes on all aspects. As the rainfall increases *E. Baxteri* appears mixed with it on the southern aspect with pink gum pure on the northern aspect, and with further rainfall increases *E. Baxteri* occurs with it on both aspects. At about 35 inches per annum, as mentioned above, *E. obliqua* appears and the pink gum tends to be confined to the drier aspects, the size of the area it occupies becoming progressively smaller until only a few scattered trees occasionally occur within the "stringybark complex" at about the 40-inch isohyet. The fact that the 40-inch isohyet is approximately the species' upper limit explains its absence on soils of low nutrient status between Stonyfell Ridge and National Park. The soil and rainfall requirements of *E. fasciculosa* are illustrated in fig. 11.

As this species occupies only small areas in the broad survey carried out by Crocker in the South-East (6) little comparison can be made. One author (Specht) however, has noted on the leached sands of the South-East, that as the rainfall decreases *E. fasciculosa* tends to become more prevalent and to supplant *E. Baxteri*. On the eastern side of the Mount Lofty Ranges Jessup (11) has shown that the species occurs over relatively rich red-brown earths in a rainfall as low as 15 inches per annum. This seems anomalous compared with the environmental range found on the western side.

8. *E. cosmophylla* (scrub or cup gum)

E. cosmophylla occurs in limited areas throughout the "stringybark complex" with rainfall between 35 inches and 45 inches per annum, principally on podsolic and lateritic soils and always on the sunny aspects of the ridges (see fig 11). A pure community occurs on a steep north-facing quartzite slope in Waterfall Gully and in the Brownhill Creek watershed. The species tends to be limited in extent because of competition with other taller Eucalypts which obstruct the sunlight. Thus *E. cosmophylla* tends to develop on very skeletal soils where the scarcity of soil restricts the number of other Eucalyptus species developing. The fact that the direct effect of insolation is a marked controlling factor is supported by the occurrence of scrub gum on only the sunny aspects, no matter what the rainfall. Taking into account the difference in topography this environmental range corresponds to that found on Kangaroo Island by Baldwin and Crocker (2). On Kangaroo Island the direct effect of isolation does not apply, for the area is a lateritic peneplain.

9. *Eucalyptus rubida* (candle-bark or white gum)

This species occupies a considerable area around gully heads on highly leached grey-brown podsols with a rainfall greater than 45 inches per annum. As the annual rainfall decreases to 35 inches the species is confined to a narrow belt of wet alluvial soil along the larger creeks. Its distribution in relation to soil and rainfall is illustrated in fig. 10.

10. *Eucalyptus elaeophora* (bastard box)

As this species only makes its appearance in the extreme north of the area no attempt has been made to determine its environmental range. This will be dealt with in a later paper. In this area the bastard box occurs on podsols and ferrimorphic soils of low nutrient status.

11. *Casuarina stricta* (drooping sheoak)

This species occurs scattered amongst *E. odorata* and *E. leucoxylon* on various soils from the coast to about the 35-inch isohyet. On very steep cliffs such as occur in the Torrens Gorge, Morialta, Slape's Gully, near the first waterfall in Waterfall Gully, the Sturt and Onkaparinga gorges, pure communities may be developed on either aspect. The sheoak occurs with *Banksia* near Noarlunga and Hackham on deep siliceous sands of neutral reaction and of low water-retaining capacity with a rainfall 20 to 22 inches. From this evidence it appears that *Casuarina stricta* can exist in much drier habitats than *E. odorata*, which often occurs in contiguous habitats which are less steep or, as in the case of the deep sands, of higher water-retaining capacity. This evidence is supported by the occurrence of *Casuarina stricta* on shallow gneissic soils along the dry Palmer scarp on the east of the Mount Lofty Ranges, with a rainfall of 20 inches per annum. This stand extends to the south, where it occurs on very shallow red-brown earths (with terra rossa affinities) around Lake Alexandrina (Jessup 11). Here the rainfall is about 15 inches per annum. On Eyre Peninsula Crocker (7) has found the species occurring over calcimorphic soils and skeletal gneissic soils from 14 to 22 inches per annum.

Crocker (6) has also found *Casuarina stricta* associated with sandy terra rossas in the South-East, where the rainfall is as high as 28 inches per annum. These observations suggest that *Casuarina stricta* can exist over a wide range of soils in respect of reaction, nutrient status and texture, but appears to be limited to those conditions in which the compensating moisture relations are low.

12. *Hybrids*

Hybrids between different species of Eucalyptus have been found especially at the junction of the distribution of two species. These hybrids possess characters intermediate between the two parent species, making identification of some trees difficult. Such a case occurs between *E. viminalis* and *E. camaldulensis* giving rise to trees with anomalous *E. viminalis* fruits, and between *E. viminalis* and *E. rubida*, thus forming stands of trees which gradually grade from one species into another.

Hybrids also occur between *E. viminalis* and *E. leucoxylon*, *E. obliqua* and *E. Baxteri*, *E. odorata* and *E. leucoxylon*, and *E. camaldulensis* and *E. leucoxylon*.

13. *Formations*

As is the case of the species of the first stratum, the undershrubs exist over a definite environmental range, some being ecological wides, others having a limited range. In general there are two definite formations—the savannah woodland formation being developed over soils rich in P_2O_5 and nitrogen, such as red-brown earths, calcimorphic soils and the slightly leached grey-brown podsols, while a sclerophyllous formation occurs on more heavily leached grey-brown podsols, podsols, laterites and ferrimorphic soils which are lower in P_2O_5 and nitrogen. On the grey-brown podsols a transition between savannah and sclerophyll occurs. This is probably connected with increased leaching with increased rainfall. However, an abrupt change occurs at the junction between richer soils and podsols. Within the formations, variation within the under-

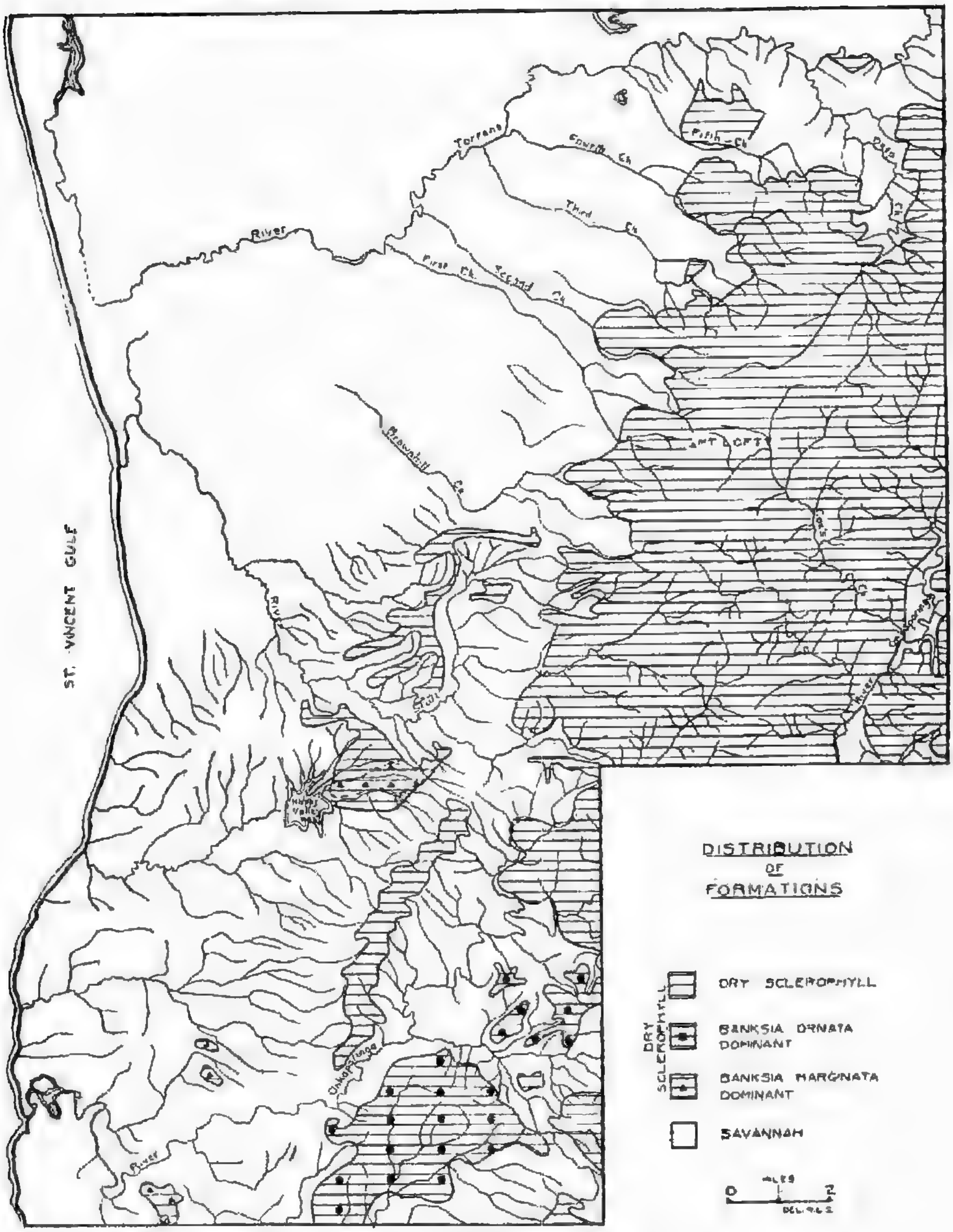


Fig. 12
Map showing the distribution of the formations.

shrubs occurs with every microhabitat, some species being dominant in one locality, others in another, but throughout the formation the same composition usually occurs. *Conospermum patens* and *Hypolaena fastigiata* are restricted to the residual laterite on the Eden-Moana fault block, while *Banksia ornata* appears on the deep lateritic sands on the Ochre Cover fault block. In all cases the formations are developed independently of the dominant trees.

Some characteristic species (*e.g.*, *Hibbertia acicularis*, *Olearia ramulosa*, etc.) are ecological wides and occur throughout the savannah and sclerophyll, but extreme splitting would come into ecological classification if these species were taken into account. Further investigation, however, is warranted into the autecology of individual species of the lower strata.

The distribution of the formations is indicated in fig. 12 and in pl. VI.

B. Classification of the Plant Communities

In classifying plant communities the authors have adhered as closely as possible to the scheme proposed by Wood (9). An association is defined as any natural group of species occurring in similar habitats. When there is a modification of only the dominant tree stratum of an association by a small change in environment, these stands are called vegetation types of the association. If, however, the associated undershrubs change with the microhabitat over a small area while the tree stratum of the association remains the same, these stands are termed societies of the association. The term community is used for any assemblage of plants. All the communities appear to be climax communities, the only communities showing seral relationships occurring in the swamps and sandhills or as stages in the regeneration of forests after clearing and burning.

The vegetation has been classified into nine associations, the relationships and environments of which are summarised in Table I.

1. *Eucalyptus odorata* association (see pl. VIII, fig. 3)

Within the rainfall limit of 30 inches per annum a pure association of *E. odorata* savannah woodland occurs over red-brown earths, calcimorphic soils, and grey-brown podsols. Over all this area *E. odorata* grows to a small tree less than 30 feet in height or may assume a "mallee" habit. Associated with it and sometimes codominant are *Melaleuca pubescens* (on the calcimorphic soils) and *Casuarina stricta*, both of which are small trees. *Acacia pycnantha* also forms a distinct second stratum with grasses such as *Danthonia* spp., *Stipa* spp. and *Themeda australis*, usually constituting the ground stratum. However, the savannah woodland has been invaded by a large number of introduced plants, which in many cases alter the facies of the association, *e.g.*, olive (*Olea europaea*), hawthorn (*Crataegus monogyna*) or dog rose (*Rosa canina*), but usually the facies is little changed, for even though the invaders are numerous they are small.

The land on which this association occurs is some of the best in the area. Much of it has been cleared and is now being used for cereal growing, vineyards and grazing.

A floristic list is given in Appendix II.

2. *Eucalyptus leucoxylon*—*Eucalyptus viminalis* association

This association lies between the 30 and 35-inch isohyets on grey-brown podsols and truncated laterites, *E. leucoxylon* occupying the drier northern aspect of the ridges between the 30- and 35-inch isohyets, with *E. viminalis* on the moister southern aspects. The undershrubs are essentially the same as in the *E. odorata* association, with *Hibbertia acicularis* and *Olearia ramulosa* more prevalent. The undershrubs show no variation at all with aspect. Hence as these two *Eucalyptus* species tend to occur mixed on the tops of the ridges and further south, it is best to look upon these pure stands with similar undershrubs, as *E. leucoxylon* and *E. viminalis* woodland types differentiated by microhabitats within the *E. leucoxylon*—*E. viminalis* association.

Between the 25- and 30-inch isohyets *E. leucoxylon* occupies the moister southern aspect either alone or mixed with *E. odorata*. *E. odorata* then occurs

on the drier northern aspect. These pure *E. leucoxylon* savannah woodland stands may be considered as an *E. leucoxylon* type of the above association, for it occupies a similar microhabitat. However, although the mixed savannah stand of *E. leucoxylon* and *E. odorata* occupies a similar place to the *E. leucoxylon* type, it must be considered as an ecotone between the two associations.

3. *Eucalyptus camaldulensis* association (see pl. VIII, fig. 1)

This association is well defined. As the distribution and the environmental range of *E. camaldulensis* has been discussed above, there is no need for recapitulation. Along the creek beds *Cyperus vaginatus*, together with *Juncus pallidus* and *J. polyanthemos*, are the dominant plants. Occasionally *Cytisus canariensis* and *Rubus fruticosus* have invaded the association in the wetter regions. However, away from the creeks the vegetation is of the same savannah type as occurs within the *E. leucoxylon – E. viminalis* association. In the watercourses amongst the lateritic sands *Leptospermum pubescens, Melaleuca decussata, Callistemon salignus, Acacia rhetinoides*, and *A. verniciflua* occur as well as the species mentioned above.

4. *Casuarina stricta* association (see pl. IX, fig. 4)

This association occurs in limited areas of extremely low water relationships, such as steep rocky slopes and the deep siliceous sands of neutral reaction near Noarlunga and Hackham, where the rainfall is just over 20 inches per annum. On these deep siliceous sands *Banksia marginata* and, in some places, *Callitris propinqua*, are codominant. Here the association is definitely sclerophyllous, the most important plants being *Xanthorrhoea semiplana* and *Adenanthos terminalis*. Other common shrubs are *Dodonaea viscosa, Bursaria spinosa, Olearia ramulosa, Exocarpus cupressiformis, Calythrix tetragona, Acacia pycnantha, A. armata, Banksia ornata, Hibbertia stricta, Grevillea lavandulacea*, and *Kennedya prostrata*. *Asclepias rotundifolia* and *Solanum sodomaeum* have invaded the area. *Scirpus nodosus* and *Lepidosperma carphoides* are fairly common, while *Muehlenbeckia adpressa, Carpobrotus aequilaterale*, and *Adenanthos terminalis* occupy large areas of ground. Of the herbaceous plants *Oenothera odorata* and *Salvia verbenaca* are common, while the grasses *Enneapogon nigricans, Themeda australe* and *Briza maxima* occur sparingly. *Loranthus Miquelii* sometimes infests *Casuarina* stricta.

On steep slopes the association approaches a sclerophyllous community, *Xanthorrhoea quadrangulata* in particular being dominant. *Exocarpus cupressiformis, Bursaria spinosa, Dodonaea viscosa, Olearia ramulosa, Banksia marginata, Asclepias rotundifolia* and *Osteospermum moniliferum* are often prevalent, together with ferns such as *Cheilanthes tenuifolia* and *Pleurosorus rutifolius* and the grasses *Themeda australis, Stipa setacea* and *Danthonia semiannularis*. *Loranthus exocarpi* occurs occasionally on *Casuarina stricta* and *Exocarpus cupressiformis*.

From the nature of the *Casuarina stricta* association it seems that it could be classed as an extremely dry association of the "stringybark edaphic complex." In some parts, however, it has closer affinities to a savannah woodland formation, while according to Wood (24) a savannah woodland formation of *Casuarina stricta* occurs on rendzinas near Port Noarlunga.

5. *"Stringybark edaphic complex"* (see pl. VIII, fig. 2, 3, 4, and IX, fig. 1, 2, 3).

On soils low in nutrient status, provided the water relations do not permit the development of *E. odorata* or *E. leucoxylon*, there occur six species of Eucalyptus (namely *E. fasciculosa, E. Baxteri, E. obliqua, E. cosmophylla*,

E. rubida and *E. elaeophora*) whose environmental ranges coincide with the habitats found within this section. All of these six species are extremely sensitive to small changes in environment. As shown above, the distribution of all is controlled by the moisture relationships within the soil and the nature and/or the P_2O_5 and nitrogen level of the soil, while *E. cosmophylla* is probably controlled by insolation.

In dissected country, especially with a complex pedology such as occurs in the Adelaide Hills, a large number of micro-habitats occur every few chains. Each microhabitat is favourable for the development of a certain combination of *Eucalyptus* species and undershrubs whose autecology coincides with the conditions at that spot. Thus we have a large number of combinations of species produced, each occupying only a limited area (which is often quite small but may be up to a couple of square miles in extent).

Hence, within the area, it is possible to distinguish the combinations of Eucalyptus species which occur in similar habitats which are set out in Table II.

TABLE II

On podsols and laterites	On grey-brown podsols
E. obliqua	*E. obliqua*
E. obliqua – E. Baxteri	*E. obliqua – E. fasciculosa*
E. obliqua – E. Baxteri – E. fasciculosa	*E. obliqua – E. rubida*
E. obliqua – E. Baxteri – E. cosmophylla	*E. fasciculosa – E. cosmophylla*
E. obliqua – E. Baxteri – E. cosmophylla – E. fasciculosa	*E. fasciculosa*
E. obliqua – E. fasciculosa	*E. rubida*
E. obliqua – E. fasciculosa – E. cosmophylla	
E. Baxteri – E. fasciculosa	**On ferrimorphic soils**
E. Baxteri – E. fasciculosa – E. cosmophylla	*E. elaeophora*
E. Baxteri – E. cosmophylla	*E. elaeophora – E. fasciculosa*
E. fasciculosa	*E. elaeophora – E. obliqua*
E. cosmophylla	*E. obliqua*

In general the undershrubs constitute a sclerophyllous community of remarkably constant composition no matter what the combination of dominant trees, although the frequency of the individual species varies with the micro-habitats. However, these changes in the frequency of the species may occur within a single combination of *Eucalyptus* species as well as between combinations, thus giving little significance to the use of the undershrubs in an attempt to classify the communities under discussion.

A glance at the map of the distribution of the six *Eucalyptus* species in the area under discussion reveals the extreme difficulty of formulating a satisfactory system of classification of the combinations of these species. Considering the variability of the micro-habitats over a small area, it seems justifiable to consider areas containing these species where a more uniform habitat exists. Such a case is found on the more level topography of the lateritic peneplain of Kangaroo Island and the sand-dune ranges of the South-East. On Kangaroo Island *E. Baxteri – E. cosmophylla* sclerophyll association is present over a wide area with *E. obliqua*, *E. Baxteri* and *E. cosmophylla* occurring mixed in the wetter regions (2). In the South-East, *E. Baxteri* sclerophyll association occurs over wide areas of a uniform edaphic condition with *E. obliqua* occurring on the better soils with a rainfall greater than 24 inches per annum (6). We therefore see

that under a more uniform habitat the same species (both trees and undershrubs) will be present in the same combination and frequency over a wide area and can be classified as an association. On close examination of the Adelaide Hills the *E. obliqua*–*E. Baxteri* association of the South-East and the *E. Baxteri*–E. cosmophylla association of Kangaroo Island are apparent over small areas where an analogous environment is present.

As *E. fasciculosa* occurs pure in large areas toward the drier limit of the complex it seems logical to class this as an association. *E. obliqua* also tends to occur pure over the highly leached grey-brown podsols. Definite areas of *E. rubida* occur along the watercourses in a rainfall of 35 to 45 inches per annum, and in larger areas on grey-brown podsols in the wetter regions. Hence we could separate an *E. obliqua* association and an *E. rubida* association, but for further evidence to support these last two associations we shall have to look to the eastern States.

It is seen that within the "stringybark edaphic complex" there are possibly at least five associations, namely:—

E. obliqua association
E. obliqua–*E. Baxteri* association
E. Baxteri–*E. cosmophylla* association
E. fasciculosa association
E. rubida association

As only the southern limit of *E. elaeophora* occurs in the area, no conclusion can be reached as yet as to its status in the "stringybark complex".

The other combinations may be regarded as forest types or ecotones of the above associations.

The dominant undershrubs of this dry sclerophyllous edaphic complex vary from place to place independently of the tree species. Usually about six species (*Acacia myrtifolia, Pultenaea daphnoides, Leptospermum scoparium, Epacris impressa, Hakea rostrata, Xanthorrhoea semiplana*) appear to be codominant, but local variations in percentage frequency occur. On the grey-brown podsols *Daviesia corymbosa* tends to become a codominant undershrub as well. On the deeper residual lateritic podsols near Blewitt's Springs with a rainfall of 25 to 30 inches per annum *Banksia ornata* becomes a codominant undershrub, while under swampy conditions *Banksia ornata* is replaced by *Callistemon* spp. Often *Pteridium aquilinum* and grasses have become dominant on the highly leached grey-brown podsols and laterites after clearing.

A floristic list is given in Appendix II.

Cytisus canariensis, Ulex europaeus and *Rubus fruticosus* have invaded the complex in places, especially along the roads.

The moist shady valleys of Waterfall Gully tend to develop a peaty swamp vegetation with dense stands of *Leptospermum pubescens, Gahnia trifida* and *Goodenia ovata*, while on the edges occasional *Utricularia dichotoma, Sprengelia incarnata* and the fern *Schizaea fistulosa* occur. It is within these swamps that specimens of *Todea barbara* occur. The swamps do not persist far down the creek but give way to moist regions which support dense mats of ferns such as *Gleichenia circinata, Blechnum capense, B. discolor, Adiantum aethiopicum* and *Pteridium aquilinum*, together with an occasional specimen of *Asplenium flabellifolium* and *Pleurosurus rutifolius*. Similar swampy creeks are found near Longwood.

In the creeks near Heathfield large quantities of *Aponogeton distachyus* (Cape pond weed) and *Lemna minor* can be found in spring.

6. *Ecotones*

(1) Ecotones, in the sense of transition zones rather than tension belts, occur between all the associations, but especially along the junction of the "Stringybark

edaphic complex" and other associations, as here we have seven Eucalypt species with overlapping environmental ranges.

(2) *E. odorata – E. leucoxylon – E. fasciculosa* ecotone. *E. leucoxylon* and *E. odorata* have overlapping environmental ranges between the 25" and 30" isohyets on both the grey-brown podsols and laterites of the Eden-Moana Fault Block. Towards the drier limit *E. leucoxylon* occupies the shady moister aspect of the ridges, whereas towards the wetter it spreads out over both aspects. *E. odorata* is here unaffected by aspect and occurs mixed with *E. leucoxylon* up to the 30" isohyet. Such stands occur on the Eden-Moana Fault Block from Happy Valley Reservoir to National Park. As shown above, the nutrient status of grey-brown podsols and laterites is different, the laterites being low whereas the grey-brown podsols are relatively high. Consequently, although the *Eucalyptus* species are not affected, the undershrubs are respectively those associated with sclerophyllous and savannah communities. On the shallow lateritic residual podsols of the Ochre Cove Fault Block an *E. leucoxylon* sclerophyllous community containing a few isolated trees of *E. fasciculosa* merges into the *E. fasciculosa* association of the "stringybark-edaphic complex" on the deeper lateritic residual podsols. This association contains an occasional tree of *E. leucoxylon*. Throughout the areas of blue gum and peppermint gum mentioned above, small areas of an *E. viminalis* sclerophyllous community occur.

The difficulty arises in classifying such stands. As the *E. leucoxylon – E. odorata* sclerophyllous community has a constant structure over a considerable area, one could look upon this as an association, with the *E. leucoxylon* sclerophyllous stand, such as occurs on the Ochre Cove Fault Block and at Happy Valley Reservoir, as a sclerophyllous woodland type within the association. However, as pointed out above, there is a marked change in the undershrubs independently of the associated trees, so that *E. leucoxylon – E. odorata* savannah and *E. leucoxylon – E. odorata sclerophyllous* woodlands occur contiguously over considerable areas. This change in the undershrubs is too vast to allow the stands to be classified as societies within the same association. The presence of patches of *E. viminalis* throughout, and occasional trees of *E. fasciculosa* in the stands on the Ochre Cove Fault Block, provides further evidence that the stands do not constitute an association. It therefore seems better to regard the stands as an ecotone between the three associations, occurring at its limits, *i.e.*, the *E. odorata* savannah woodland association, the *E. leucoxylon – E. viminalis* savannah woodland association, and the *E. fasciculosa* sclerophyll woodland association.

The species composition of the savannah stands is similar to that of the *E. odorata* association. In the sclerophyllous stands several undershrubs are co-dominant. On the Eden-Moana Fault Block *Banksia marginata, Adenanthos terminalis* and *Kunzea pomifera* are prevalent in the south on the deeper residual laterite whereas *Xanthorrhoea semiplana, Hakea rostrata* and *H. ulicina* are prevalent in the north on truncated laterite. A list of the species present in the sclerophyll stand is given in the appendix.

The "whipstick mallee" form of *E. odorata* on the podsol at the foot of Black Hill could possibly be classed within this ecotone.

7. *Miscellaneous communities which occupy only small areas*

(1) *Coastal Sandhill communities*

At Port Noarlunga and Christie's Beach there are small areas of sandhills on which distinct communities develop.

A. At Port Noarlunga the dominant plants are three shrubs, *Acacia longifolia, Myoporum insulare* and *Olearia axillaris,* which all grow to a height of

4 to 6 feet. The most important associated plants are *Calocephalus Brownii, Leucopogon parviflorus, Arctotis stoechadifolia, Muehlenbeckia adpressa, Cakile maritima, Carpobrotus aequilaterale, Rhagodia baccata, Suaeda australis, Spinifex hirsutus* and *Scirpus nodosus*. Others which occur much less frequently are *Dianella revoluta, Scaevola crassifolia, Kennedya prostrata, Pimelea serpyllifolia, Lotus australis, Luzula campestris* and the grass *Lagurus ovatus*. It should be noted that a large proportion of these plants are prostrate creeping plants. All the plants are stunted and dwarfed owing to the poor and saline nature of the soil and the exposed position.

B. *At Christie's Beach* there is a smaller area of dunes which are not as well stabilised as those at Port Noarlunga. The flora is not as well developed, the dominant and sometimes only plant being *Ammophila arenaria*. Other plants are infrequent, but the following do occur:—*Acacia longifolia, Olearia axillaris, Dianella revoluta* and *Euphorbia terracina*.

(2) *Coastal cliff communities*

With the exception of the two small areas of sandhills mentioned above the coastline is generally marked by cliffs, the vegetation of which, besides being extremely variable, is scattered and stunted owing to the exposed conditions and shallow soils. The chief shrubs present are *Alyxia buxifolia, Myoporum insulare, Olearia ramulosa, Beyeria Leschenaultii, Nitraria Schoberi, Acacia ligulata, A. longifolia, Eutaxia microphylla, Atriplex paludosum, Enchylaena villosa, Rhagodia baccata, Pomaderris racemosa, Melaleuca decussata*, and *Westringia rigida*. Other plants which commonly occur are *Carpobrotus aequilaterale, Scaevola microcarpa, Myoporum parvifolium, Zygophyllum Billardieri, Kennedya prostrata, Dampiera rosmarinifolia, Dianella revoluta, Cakile maritima, Oenothera odorata, Asphodelus fistulosus* and *Velleia paradoxa*.

(3) *Coastal Swamps*

Near the mouth of the Onkaparinga river there is a small area of saline swamp, some of which is subject to flooding at high tides. This small area contains the best example of succession found during the survey. The sere can be illustrated as follows:—

Arthrocnemum sp.

↓

Arthrocnemum sp.—*Salicornia* sp.

↓

Salicornia sp.—*Atriplex paludosum*

↓

Atriplex paludosum—*Nitraria Schoberi*

The direction of the arrows indicates deeper water table, decreasing salinity and less frequent flooding.

A. In the lowest areas which are subject to flooding at high tides *Arthrocnemum* sp. is the first plant to become established. The spreading habit of this plant leads to a gradual raising of the ground level due to collection of alluvial material.

B. On the slightly higher areas not subject to such frequent flooding *Salicornia* sp. becomes codominant with *Arthrocnemum.* Associated with these two plants is *Samolus repens.*

C. Where flooding is rare and only occurs at exceptionally high tides *Arthrocnemum* is not so important although still present. The dominants in this part are *Salicornia* sp. and *Atriplex paludosum.* Associated with them are *Samolus repens, Plagianthus microphyllus, Kochia oppositifolia, Frankenia pauciflora,* and *Carpobrotus aequilaterale.*

D. The highest parts of the swamp are only flooded by the infrequent fresh-water floods caused by overflowing of the Onkaparinga River. A more complete vegetative cover is present. The dominants are *Nitraria Schoberi* and *Atriplex paludosum,* and associated with them are *Salicornia* sp., *Arthrocnemum* sp., *Enchylaena villosa, Suaeda australis, Rhagodia baccata, Plagianthus microphyllus, Wilsonia humilis, Carpobrotus aequilaterale, Frankenia pauciflora* and *Distichlis spicata. Juncus maritimus* is common in some parts.

SUMMARY

This paper deals with the ecology of portion of the Mount Lofty Ranges between the River Torrens and Noarlunga.

Working on the premise that every plant has a certain potential environment, the climate, soils and vegetation have been studied and attempts made to correlate the distribution of the dominant trees and association with the environment.

Both mechanical and chemical analyses have been made on soil samples typical of each of the soil groups present in the area, and suggestions are given as to the genesis of each soil.

To add breadth to any conclusions drawn from the data collected, the environmental range of the dominant species is discussed with reference to their environment in other parts of South Australia which have been studied by other ecologists.

ACKNOWLEDGMENTS

It would be impossible here to satisfactorily acknowledge the great assistance which has been so willingly given in this research by a large number of people. We can sincerely say that their help has been greatly appreciated. In particular we would like to express our appreciation of the help and advice which has been so readily given by Professor J. G. Wood.

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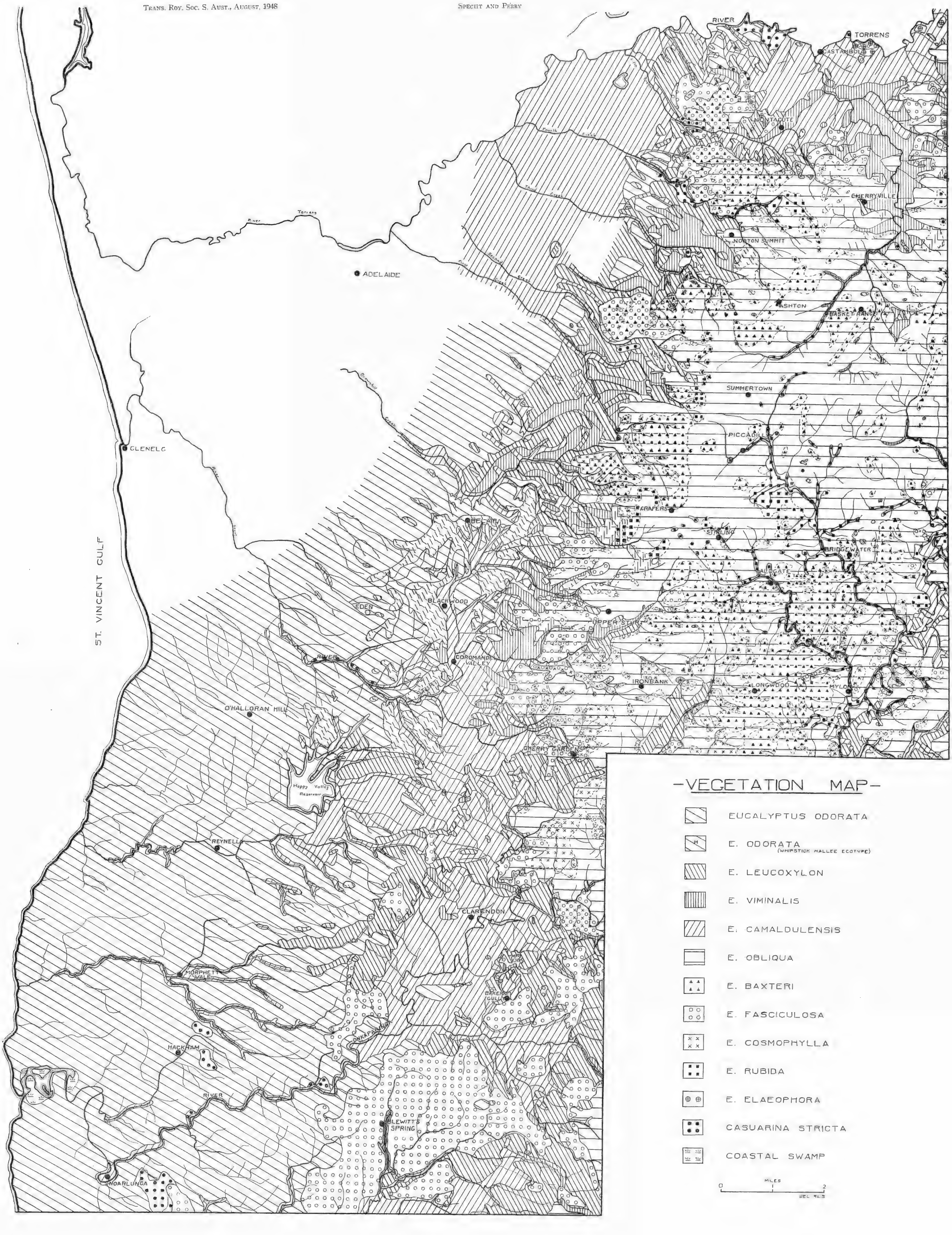
-VEGETATION MAP-
EUCALYPTUS ODORATA
E. ODORATA (WHIPSTICK MALLEE ECOTYPE)
E. LEUCOXYLON
E. VIMINALIS
E. CAMALDULENSIS
E. OBLIQUA
E. BAXTERI
E. FASCICULOSA
E. COSMOPHYLLA
E. RUBIDA
E. ELAEOPHORA
CASUARINA STRICTA
COASTAL SWAMP
MILES
0 1 2
ST. VINCENT GULF
ADELAIDE
GLENELG
TORRENS
RIVER
CHERRYVILLE
NORTON SUMMIT
ASHTON
BASKET RANGE
SUMMERTOWN
PICCADILLY
CRAFERS
STIRLING
BRIDGEWATER
ALDGATE
BLACKWOOD
EDEN
UPPER STURT
COROMANDEL VALLEY
IRONBANK
LONGWOOD
O'HALLORAN HILL
CHERRY GARDENS
Happy Valley Reservoir
REYNELLA
CLARENDON
MORPHETT VALE
HACKHAM
NOARLUNGA
BLEWITTS SPRING
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APPENDIX I

Results of mechanical and chemical analyses of soil profiles typical of soils within the area.
The grid references give the localities on the Echunga and Adelaide military ordnance maps.

Grey-brown Podsols and Allied Soils

Locality	Happy Valley Reservoir			Brownhill Creek				Upper Sturt			Summertown	
Grid reference	578656			660773		670790		690730			717810	
Horizon	A	B	B	A	B	A	B	A	B	C	A	B
Depth (inches)	0–10	10–15	15–27	0–8	8–16	0–10	10–20	1–15	15–28	28–36	0–12	12–48
	%	%	%	%	%	%	%	%	%	%	%	%
Coarse sand	28·0	13·0	15·7	16·8	4·0	11·1	2·0	14·2	1·8	5·2	8·3	2·1
Fine sand	35·5	16·5	11·3	40·3	31·0	38·4	24·2	47·3	20·6	31·2	43·2	18·3
Silt	12·5	8·5	8·0	26·7	21·3	23·0	17·6	21·5	27·5	29·2	30·7	17·1
Clay	24·0	62·0	64·5	16·3	43·7	27·5	56·2	17·4	50·1	34·4	17·8	62·5
Gravel	0	0	0	0	0	38	0	28	0	0	60	0
P_2O_5	·048	—	—	·063	·052	·071	—	·021	—	—	·021	·019
Nitrogen	·114	·051	·023	·268	·086	·19	·063	·051	·024	—	·075	·038
Reaction pH	*8·0	8·1	8·0	†7·5	7·6	5·2	5·2	5·3	5·4	5·4	5·9	5·6

* Allied to red-brown earths. † Near limestone.

Podsols

Locality	Ackland's Hill			Mt. Lofty		Mt. Lofty Summit		Noarlunga			Long Ridge*		Glen Osmond*
Grid reference	660700			710744		710795		534525			690810		658786
Horizon	A	B	C	A	B	A	B	A	A	B	A1	A2	A
Depth (inches)	1–20	20–34	34+	0–12	12–48	0–16	16–36	0–6	6–12	12–20	0–18	18+	0–12
	%	%	%	%	%	%	%	%	%	%	%	%	%
Coarse sand	59·0	29·6	65·5	65·2	22·8	70·4	28·7	76·0	74·0	15·5	62·8	72·6	57·0
Fine sand	31·0	12·5	10·4	23·8	12·2	17·8	11·3	13·0	15·0	11·0	24·8	18·8	28·8
Silt	5·0	19·6	9·3	6·0	9·5	5·1	9·0	6·5	6·0	5·5	7·9	4·3	7·5
Clay	29·6	38·3	14·8	5·0	55·5	6·7	51·0	4·0	5·0	68·0	4·5	4·3	6·7
Gravel	53·0	0	0	27	0	44	0	0	0	0	0	0	48
P_2O_5	·0036	—	—	·0066	—	·0044	—	·0086		—	·035	—	·015
Nitrogen	·021	·018	—	·057	·054	·040	·042	·090	·017	—	·192	·017	·071
Reaction pH	6·1	5·6	4·8	6·3	5·3	5·7	5·2	6·0	6·1	5·9	6·2	5·9	5·9

* Developed over small outcrops of quartzite.

Residual Lateritic Podsols

Locality	Blackwood					Cherry Gardens				Happy Valley		
Grid reference	620690					650640				579644		
Horizon	AO	A1	A2	B	C	AO	A1	A2	B	A1	A2	B
Depth (inches)	0–2	2–15	15–36	36–58	58+	0–2	2–6	6–12	12–20	0–16	16–21	21+
	%	%	%	%	%	%	%	%	%	%	%	%
Coarse sand	36·5	38·5	35·5	28·9	9·3	70·5	63·5	57·0	20·5	53·5	51·0	14·5
Fine sand	56·5	54·5	53·5	29·3	62·2	16·5	19·0	19·0	12·5	34·5	37·0	13·5
Silt	3·0	4·0	5·5	7·0	6·0	5·0	6·0	6·5	10·0	7·5	7·5	15·5
Clay	4·0	3·0	5·5	33·8	22·5	8·0	11·5	17·5	57·0	4·5	4·5	56·5
Gravel	0	0	84	0	0	0	14	63	41	0	0	0
P_2O_5	—	·0041	—	·0077	—	—	·008	—	—	·008	—	—
Nitrogen	·069	·0079	·027	·019	—	·056	·021	·030	·036	·03	—	·06
Reaction pH	5·7	6·3	6·5	5·8	5·1	5·9	6·0	6·4	5·3	6·4	6·7	6·2

Truncated Lateritic Podsols and Deep Lateritic Sands

Locality	Cherry Gardens		Cherry Gardens				Blewitt's Springs		
Grid reference	670680		650670				502529		
Horizon	A2	B	A2	B1	B2	B3	A1	A2	A3
Depth (inches)	0–9	9–25	0–2	2–18	18–27	27+	0–6	6–14	14–36
	%	%	%	%	%	%	%	%	%
Coarse sand	33·7	1·8	19·0	1·5	2·4	0·6	88·5	84·5	83·2
Fine sand	43·6	10·8	36·5	14·0	12·6	15·7	8·5	12·0	13·3
Silt	13·7	14·2	28·5	20·0	25·0	28·2	1·0	1·0	1·0
Clay	9·0	73·2	16·0	64·5	60·0	55·5	2·0	1·5	2·5
Gravel	83	0							
P_2O_5	·021	—	—	·012	—	—		·0026	—
Nitrogen	·082	·028	·489	·062	—	—	·065	·039	·078
Reaction pH	5·6	5·7	6·7	6·1	5·3	5·0	5·2	5·5	3·0

Locality	Degraded Rendzina Reynella			Degraded Rendzina O'Halloran Hill	Rendzina Port Noarlunga	Deep neutral sands Noarlunga			Unclassified Kangarilla		Unclassified Seaview		
Grid reference	554642			560590	486575	526528			670550		584542		
Horizon	A1	A2	C	A	A				A	B	A	B1	B2
Depth (inches)	0–10	10–20	20+	0–36	0–5	0–15	15–20	20–36	0–2	2–30	0–18	18–24	24–36
	%	%	%			%	%	%			%	%	%
Coarse sand -	31·0	17·5	9·0	6·0	34·5	89·6	86·5	83·8	58·5	23·0	61·0	38·0	25·0
Fine sand - -	35·5	17·0	16·0	18·0	38·5	5·4	7·0	12·2	31·0	21·0	29·0	22·0	24·0
Silt - - -	11·5	17·5	17·0	13·8	13·0	1·0	2·0	1·0	4·8	2·0	4·0	4·0	6·0
Clay - - -	22·0	48·0	58·0	62·2	14·0	4·0	4·5	3·0	5·7	54·0	6·0	36·0	45·0
P_2O_5 - -	·062	—	—	—	·208	·0053	—	—	—	—	·044	—	—
Nitrogen - -	·207	·122	—	·068	·049	·014	·034	—	·247	·026	·040	—	·047
Reaction pH -	7·9	7·8	8·1	8·5	8·3	7·1	6·8	8·1	6·1	8·5	6·2	6·4	6·5

APPENDIX II

Comparative floristic lists are given for five major vegetational groups occurring within the area. No indication is given as to the percentage frequency of each plant, the x only indicating the presence of that species within that group. The nomenclature of the species is that given by Black (3). An asterisk before the name of a species indicates that the species has been introduced to South Australia.

	Life Form	E odorata association	E. leucoxylon-E. viminalis assoc.	Sclerophyll of E. odorata-E. leucoxylon-E. fasciculosa ecotone	Casuarina stricta association	Stringybark edaphic complex
		(1)	(2)	(3)	(4)	(5)
Adiantum aethiopicum	H	.	.	.	.	x
Cheilanthes tenuifolia	H	x	x	x	x	x
Pteridium aquilinum	G	.	.	x	.	x
Pleurosorus rutaefolius	H	.	.	.	x	.
Callitris propinqua	M	.	.	x	x	.
C. tasmanica	M	.	.	.	.	x
Themeda australis	Ch	x	x	x	x	x
Neurachne alopecuroides	H	x	.	.	.	x
*Ehrharta longifolia	H	.	.	x	.	.
Stipa variabilis	H	x	x	x	x	x
S. setacea	H	x	x	x	.	x
*Oryzopsis miliacea	H	x	x	.	.	.
*Aira caryophyllea	H	x	x	.	.	.
*Avena fatua	H	x	x	.	.	.
*Holcus lanatus	H	.	.	.	.	x
Danthonia spp.	H	x	x	.	x	x
Enneapogon nigricans	H	.	.	.	x	.
Briza maxima	H	x	x	x	.	x
B. minor	H	x	x	x	.	.
Distichlis spicata	H	x	.	.	.	.
*Vulpia myuros	H	x	x	.	.	.
*Bromus spp.	H	x	x	.	.	.
*Cynodon dactylon	H	x	x	.	.	.
*Lolium spp.	H	x	x	.	.	.
*Hordeum murinum	H	x	x	.	.	.
Cyperus vaginatus	H	.	.	.	.	x
Scirpus nodosus	G	.	.	.	x	.
Lepidosperma laterale	Ch	.	.	x	.	x
L. viscidum	Ch	.	.	.	.	x
L. semiteres	Ch	.	.	x	.	x
L. carphoides	Ch	.	.	x	x	x
Chorizandra enodes	Ch	.	.	.	.	x
Hypolaena fastigiata	H	.	.	x	.	.
Juncus pallidus	H	x	x	x	x	x
Dianella revoluta	G	x	x	x	x	x
Reya umbellata	G	x	x	x	.	x
Anguillaria dioica	G	x	x	.	.	x
Lomandra dura	Ch	.	x	x	.	x

	Life Form	E. odorata association	E. leucoxylon-E. viminalis assoc.	Sclerophyll of E. odorata-E. leucoxylon-E. fasciculosa ecotone	Casuarina stricta association	edaphic complex Stringybark
		(1)	(2)	(3)	(4)	(5)
Thysanotus Patersonii - - - -	G	.	.	.	.	x
T. dichotomus - - - - - - -	G	.	.	x	.	.
Caesia vittata - - - - - - -	G	.	.	.	.	x
Bulbine bulbosa - - - - - -	G	x	x	x	x	x
Dichopogon fimbriatus - - - -	G	.	.	x	.	.
Bartlingia sessiliflora - - - - -	H	.	.	.	.	x
Xanthorrhoea quadrangulata - - -	M	.	.	.	x	.
X. semiplana - - - - - - -	Ch	.	.	x	x	x
*Asphodelus fistulosus - - - -	G	x	x	.	.	.
Hypoxis glabella - - - - - -	G	.	x	.	.	.
Calostemma purpureum - - - -	G	x	x	.	.	.
*Sparaxis tricolor - - - - - -	G	x	x	x	.	x
*S. bulbifera - - - - - - -	G	x	x	x	.	x
*Romulea rosea - - - - - - -	G	x	x	.	.	.
*Homeria collina - - - - - -	G	x	x	.	.	.
*H. miniata - - - - - - - -	G	x	x	.	.	.
Patersonia longiscapa - - - - -	H	.	.	.	.	x
Dipodium punctatum - - - -	G	.	.	.	.	x
Thelymitra aristata - - - - - -	G	.	.	.	.	x
T. antennifera - - - - - - -	G	.	.	.	.	x
Acianthus exsertus - - - - - -	G	.	.	x	.	x
Lyperanthus nigricans - - - -	G	.	.	x	.	x
Eriochilus cucullatus - - - - -	G	.	.	x	.	x
Caladenia dilatata - - - - - -	G	.	.	.	.	x
C. deformis - - - - - - -	G	.	.	.	.	x
Glossodia major - - - - - - -	G	.	.	.	.	x
Diuris maculata - - - - - -	G	.	.	.	.	x
Pterostylis nana - - - - - -	G	.	.	.	.	x
Casuarina stricta - - - - - -	M	x	x	x	x	x
C. striata - - - - - - - -	M	.	.	x	.	x
C. Muelleriana - - - - - - -	M	.	.	x	.	x
Isopogon ceratophyllus - - - -	N	.	.	x	.	x
Adenanthos terminalis - - - -	N	.	.	x	x	.
Conospermum patens - - - -	N	.	.	x	.	x
Persoonia juniperinum - - - -	N	.	.	.	.	x
Hakea rostrata - - - - - - -	M	.	.	x	.	x
H. rugosa - - - - - - - -	N	.	.	x	.	x
H. ulicina - - - - - - - -	M	.	.	x	.	x
Banksia marginata - - - - - -	M	.	.	x	x	x
B. ornata - - - - - - - -	N	.	.	.	.	x
Grevillea lavandulacea - - - -	N	.	.	x	x	x
Exocarpus cupressiformis - - - -	M	.	.	x	x	x
Loranthus Miquelii - - - - -	E	x	x	x	x	x
L. exocarpi - - - - - - - -	E	x	x	.	x	.
*Rumex crispus - - - - - - -	T	x	x	.	.	.
*R. acetosella - - - - - - -	T	x	x	.	.	.

	Life Form	E odorata association	E. leucoxylon-E. viminalis assoc.	Sclerophyll of E. odorata-E. leucoxylon-E. fasciculosa ecotone	Casuarina stricta association	Stringybark edaphic complex
		(1)	(2)	(3)	(4)	(5)
Muehlenbeckia adpressa	N	.	.	x	x	.
Carpobrotus aequilaterale	S	.	.	.	x	.
Ranunculus lappaceus	H	.	x	.	.	.
Cassytha glabella	E	.	.	x	.	x
Drosera binata	T	x	x	x	x	x
D. glanduligera	T	x	x	.	.	x
D. Whittakeri	G	x	x	x	.	x
D. Planchonii	G	.	.	x	.	x
D. auriculata	G	.	.	x	.	x
D. peltata	G	.	.	x	.	x
Crassula Siebariana	T	.	.	.	.	x
Bursaria spinosa	M	x	x	x	x	x
Marianthus bignoniaceus	N	.	.	.	.	x
Cheiranthera linearis	N	.	.	.	.	x
Billardiera cymosa	N	x	x	x	.	x
*Rubus fruticosus	N	x	x	.	.	x
*Rosa canina	N	x	x	.	.	.
*Crataegus monogyna	N	x	x	x	.	.
Acaena ovina	H	x	x	.	.	x
A. sanguisorbae	H	x	x	.	.	x
Acacia continua	M	.	.	.	.	x
A. armata	M	x	x	x	x	.
A. obliqua	M	.	.	.	.	x
A. spinescens	M	.	.	.	.	x
A. verniciflua	M	.	.	.	.	x
A. rhetinodes	M	.	x	.	.	x
A. myrtifolia	M	.	.	x	.	x
A. pycnantha	M	x	x	x	x	x
A. rupicola	M	.	.	.	.	x
A. vomeriformis	M	.	.	.	.	x
A. melanoxylon	M	.	.	.	.	x
Daviesia corymbosa	N	.	.	x	.	x
D. ulicina	N	.	.	x	.	x
D. brevifolia	N	.	.	.	.	x
Eutaxia microphylla	N	.	.	x	.	x
Pultenaea daphnoides	N	.	.	.	.	x
P. pedunculata	N	.	.	.	.	x
P. largiflorens	N	.	.	x	.	x
P. involucrata	N	.	.	.	.	x
P. acerosa var. acicularis	N	.	.	.	.	x
Dillwynia hispida	N	.	.	x	.	x
D. floribunda	N	.	.	.	.	x
Platylobium obtusangulum	N	.	.	x	.	x
*Ulex europaeus	N	x	x	.	.	x
*Cytisus canariensis	N	x	x	x	.	x
*Trifolium procumbens	T	x	x	.	.	.

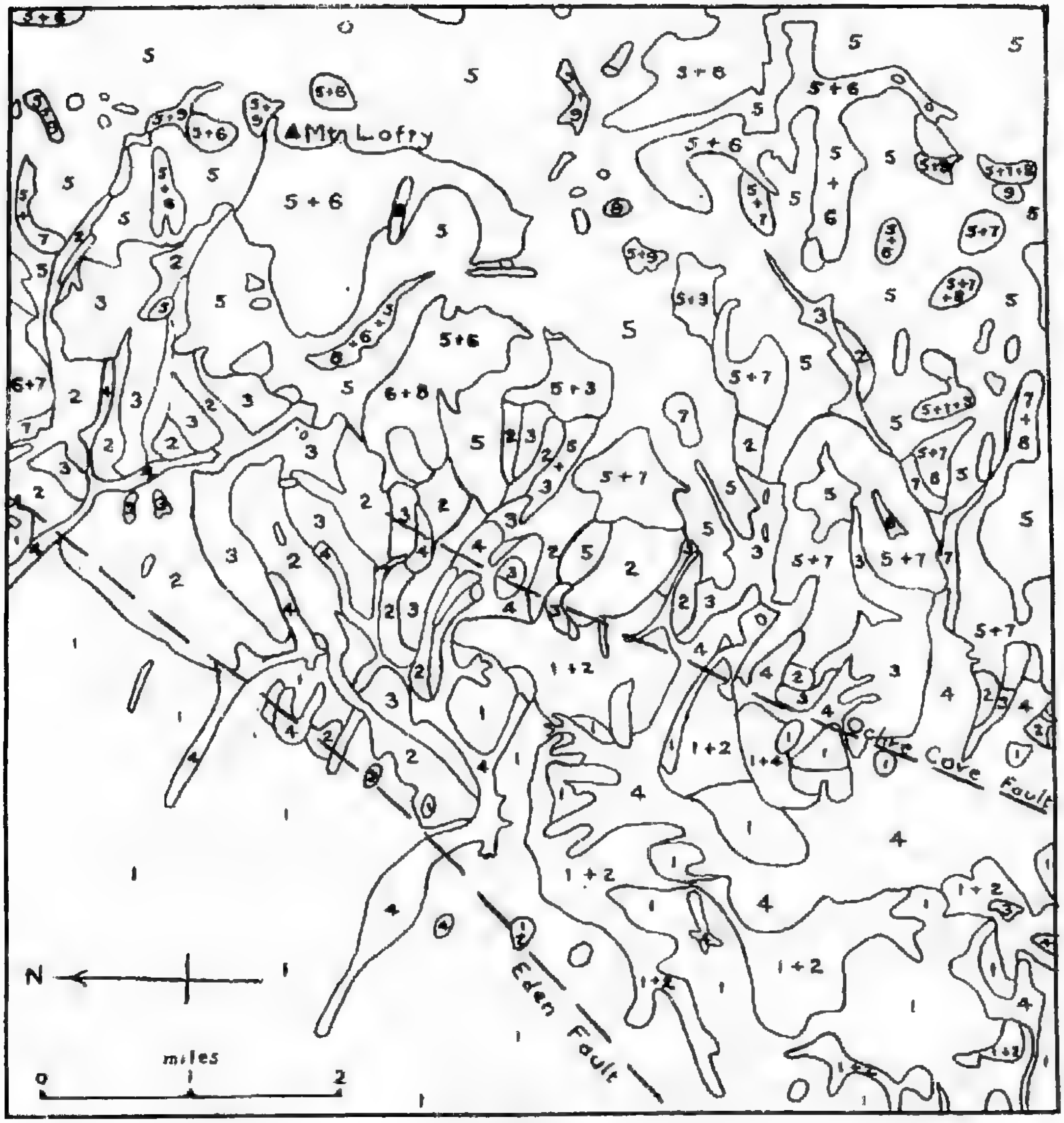
	Life Form	E odorata association (1)	E. leucoxylon-E. viminalis assoc (2)	Sclerophyll of E. odorata-E. leucoxylon-E. fasciculosa ecotone (3)	Casuarina stricta association (4)	Stringybark edaphic complex (5)
*T. subterraneum	T	x	x	.	.	.
*T. arvense	T	x	x	.	.	.
*T. angustifolium	T	x	x	x	.	.
Psoralea patens	Ch	x	.	.	.	.
Swainsona oroboides var. hirsuta	H	x	x	.	.	.
Kennedya prostrata	N	x	x	x	x	x
Hardenbergia monophylla	N	x	x	.	.	x
Glycine clandestina	H	.	.	.	.	x
*Erodium botrys	T	x	x	.	.	.
*E. moschatum	T	x	x	.	.	.
*Oxalis corniculata	G	x	x	.	.	.
*O. cernua	G	x	x	.	.	.
*Linum marginale	H	.	x	.	.	.
*L. gallicum	H	.	x	.	.	.
Boronia caerulescens	N	.	.	.	.	x
Correa rubra	N	.	.	.	.	x
Tetratheca pilosa	N	.	.	x	.	x
Adriana Klotzschii	N	x	.	.	.	.
Stackhousia monogyna	Ch	.	.	.	.	x
Dodonaea viscosa	N	x	.	.	x	.
Spyridium parvifolium	N	.	.	.	.	x
S. spathulatum	N	.	.	.	.	x
S. vexilliferum	N	.	.	.	.	x
Cryptandra tomentosa	N	.	.	x	.	x
*Malva parviflora	T	x	.	.	.	.
Hibbertia sericea	N	.	.	x	.	x
H. stricta	N	.	.	x	.	x
H. acicularis	N	.	.	x	.	x
H. virgata	N	.	.	x	.	x
*Hypericum perforatum	H	.	x	x	.	x
Hybanthus floribundus	N	.	.	x	.	x
Pimelia spathulata	N	.	.	.	.	x
P. flava	N	.	.	x	.	x
P. octophylla	N	.	.	.	.	x
Lythrum Hyssopifolia	H	.	x	.	.	.
Leptospermum scoparium	N	.	.	.	.	x
L. pubescens	N	.	.	.	.	x
L. myrsinoides	N	.	.	x	.	x
Kunzea pomifera	Ch	.	.	x	.	x
Callistemon salignus	M	.	.	.	.	x
Melaleuca decussata	N	.	.	.	.	x
M. pubescens	M	x	.	.	.	.
Eucalyptus obliqua	MM	.	.	.	.	x
E. Baxteri	MM	.	.	.	.	x
E. odorata	MM	x	.	x	.	.
E. cosmophylla	MM	.	.	.	.	x

	Life Form	E. odorata association (1)	E. viminalis assoc. E. leucoxylon. (2)	Sclerophyll of E. odorata-E. leucoxylon-E. fasciculosa ecotone (3)	Casuarina stricta association (4)	Stringybark edaphic complex (5)
E. viminalis	MM	.	x	.	.	.
E. rubida	MM	.	.	.	.	x
E. elaeophora	MM	.	.	.	.	x
E. leucoxylon	MM	.	x	x	.	.
E. fasciculosa	MM	.	.	.	.	x
Calythrix tetragona	N	.	.	x	x	x
*Oenothera odorata	T	.	.	.	x	.
Halorrhagis tetragyna	H	x	x	x	.	x
H. teucrioides	H	x	x	x	x	x
Eryngium rostratum	G	.	x	.	.	.
*Foeniculum vulgare	N	x	x	.	.	.
Astroloma humifusum	N	.	.	.	x	x
A. conostephioides	N	.	.	x	.	x
Lissanthe strigosa	N	.	.	x	.	x
Leucopogon parviflorus	N	.	.	.	.	x
L. hirsutus	N	.	.	.	.	x
L. virgatus	N	.	.	x	.	x
L. rufus	N	.	.	.	.	x
Acrotriche serrulata	N	.	.	x	.	x
A. fasciculiflora	N	.	.	.	.	x
Epacris impressa	N	.	.	.	.	x
Sprengelia incarnata	N	.	.	.	.	x
*Anagallis arvensis	T	x	x	.	.	x
*A. femina	T	x	x	.	.	.
*Olea europaea	N	x	x	.	.	.
Logania liniflolia	N	.	.	.	.	x
*Erythraea centaurium	H	x	x	.	.	.
*Asclepias rotundifolia	N	x	x	x	x	.
*Convolvulus arvensis	Ch	x	x	.	x	.
*Echium plantagineum	N	x	x	.	.	.
Teucrium racemosum	T	x	x	.	.	.
*Lavandula Stoechas	N	x	x	.	.	.
*Marrubium vulgare	N	x	.	.	.	.
*Salvia verbenaca	N	x	x	.	.	.
Prostanthera Behriana	N	.	.	.	.	x
*Stachys arvensis	T	x	x	.	.	.
*Solanum nigrum	N	x	x	.	.	.
*S. sodomaeum	N	x	x	.	x	.
*Lycium ferocissimum	M	x	.	.	.	.
*Verbascum virgatum	N	x	x	.	.	.
*Linaria Elatine	T	.	x	.	.	.
*Bartschia latifolia	T	.	.	.	.	x
*Plantago varia	T	x	x	.	.	.
*P. lanceolata	T	x	x	x	.	.
*P. coronopus	T	x	x	.	.	.
Opercularia scabrida	Ch	.	.	.	.	x

	Life Form	E. odorata association	E. viminalis assoc.- E. leucoxylon-	Sclerophyll of E. odorata-E. leucoxylon-E. fasciculosa ecotone	Casuarina stricta association	Stringybark edaphic complex
		(1)	(2)	(3)	(4)	(5)
*Sherardia arvensis	T	x	x	.	.	.
*Scabiosa maritima	Ch	x	.	.	.	.
Wahlenbergia gracilis	T	.	x	.	.	x
Lobelia gibbosa	T	.	.	.	.	x
Goodenia geniculata	Ch	x	x	.	.	.
G. primulacea	Ch	x	x	.	.	x
Velleia paradoxa	Ch	x	.	.	.	.
Scaevola microcarpa	Ch	.	.	x	.	x
Dampiera lavandulacea	Ch	.	.	.	.	x
Brunonia australis	H	.	.	.	.	x
Stylidium graminifolium	Ch	.	.	.	.	x
Brachycome exilis	Ch	x	.	.	.	.
Vittadinia triloba	Ch	x	x	.	.	.
Olearia grandiflora	Ch	.	.	.	.	x
O. ramulosa	N	x	x	x	x	x
Senecio hypoleucus	N	.	.	.	.	x
*Osteospermum moniliferum	N	x	x	x	x	x
Cryptostemma calendulaceum	T	x	x	.	.	x
Helichrysum Baxteri	Ch	.	.	.	.	x
H. scorpioides	Ch	.	.	.	.	x
H. apiculatum	Ch	.	.	.	.	x
Ixodia achilleoides	N	.	.	.	.	x
*Inula graveolens	T	x	x	.	.	.
Craspedia uniflora	H	.	.	.	.	x
*Cynara cardunculus	N	x	x	.	.	.
*Centaurea calcitrapa	T	x	x	.	.	.
*Carthamus lanatus	T	x	x	.	.	.
*Tragopogon porrifolius	T	x	x	.	.	.
*Cichorium Intybus	N	x	x	.	.	.
*Hypochoeris radicata	N	x	x	.	.	x
*Picris echioides	T	x	x	.	.	.
*Sonchus oleraceus	T	x	x	.	.	.

Raunkiaer's Life Form Key

Megaphanaerophytes	(MM)	Geophytes	(G)
Mesophanaerophytes	(M)	Helophytes	(HH)
Nanophanaerophytes	(N)	Therophytes	(Th)
Chamaephytes	(Ch)	Epiphytes	(E)
Hemicryptophytes	(H)	Succulents	(S)



– KEY –

1 E. odorata	4 E. camaldulensis	7 E. fasciculosa
2 E. leucoxylon	5 E. obliqua	8 E. cosmophylla
3 E. viminalis	6 E. Baxteri	9 E. rubida

PLATE V

Photograph of model to scale showing distribution of chief Eucalypt species in relation to topography.

EXPLANATIONS OF PLATES VI—IX

Plate VI

Fig. 1 Aerial photograph showing sclerophyll formations (dark areas) on podsols on Stonyfell Ridge as compared with savannah woodland on grey-brown podsols on Greenhill and Long Ridge to the South.

Fig. 2 Aerial photograph showing sclerophyll forest on podsols on Black Hill and Rocky Hill (Morialta area) compared with savannah woodland on grey-brown podsols near Montacute Road.

Plate VII

Fig. 1 *E. leucoxylon* savannah woodland on the north-facing slope ½ mile above Devil's Elbow.

Fig. 2 *E. viminalis* savannah woodland on the south-facing slope ½ mile above Devil's Elbow.

Fig. 3 *E. leucoxylon* sclerophyll association on truncated lateritic soils.

Fig. 4 *E. leucoxylon—Banksia marginata* association on the deep sandy soils near Happy Valley reservoir.

Plate VIII

Fig. 1 *E. camaldulensis* savannah woodland near Blackwood.

Fig. 2 *E. fasciculosa* sclerophyll scrub on truncated lateritic soils near Chandler's Hill.

Fig. 3 *E. odorata* sclerophyll association in National Park.

Fig. 4 *E. Baxteri* sclerophyll forest near Mt. Lofty summit.

Plate IX

Fig. 1 *E. obliqua* sclerophyll forest near Mt. Lofty summit.

Fig. 2 *E. cosmophylla* sclerophyll association in Waterfall Gully.

Fig. 3 *E. rubida* association on grey-brown podsols (low nutrient status) at Picadilly Valley.

Fig. 4 *Casuarina stricta* association on deep neutral sandy soils between Hackham and Morphett Vale.

Fig. 1

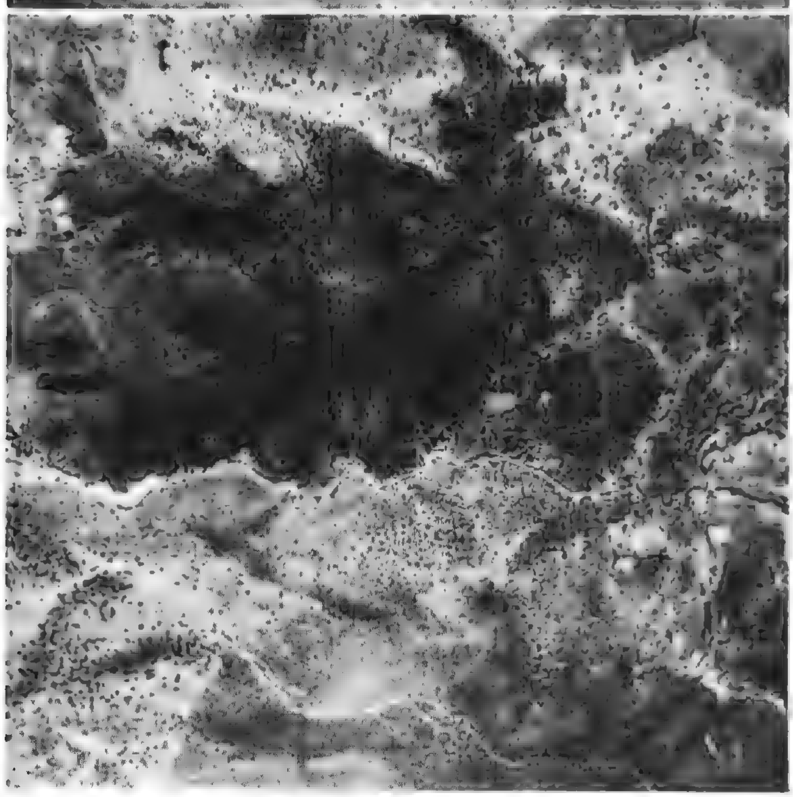


Fig. 2

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 2

Fig. 4

Fig. 1

Fig. 3

Fig. 1

Fig. 2

Fig. 3

Fig. 4

INDO-PACIFIC INFLUENCES IN AUSTRALIAN TERTIARY FORAMINIFERAL ASSEMBLAGES

By Irene Crespin

Summary

A recent examination of the microfaunal content of samples from numerous bores drilled in the Adelaide Plains by the Department of Mines, South Australia, has revealed some interesting information about the palaeogeography and stratigraphy of Tertiary sediments in Australia. Certain forminiferal assemblages and zonal foraminiferal species have been discovered in the Tertiary sub-surface deposits in the Adelaide Basin which indicate an extension to Southern Australia of Indo-Pacific conditions in Upper Middle Miocene and Lower Pliocene times.

INDO-PACIFIC INFLUENCES IN AUSTRALIAN TERTIARY FORAMINIFERAL ASSEMBLAGES [1]

By Irene Crespin

[Read 10 June 1948]

I. INTRODUCTION

A recent examination of the microfaunal content of samples from numerous bores drilled in the Adelaide Plains by the Department of Mines, South Australia, has revealed some interesting information about the palaeogeography and stratigraphy of Tertiary sediments in Australia. Certain foraminiferal assemblages and zonal foraminiferal species have been discovered in the Tertiary sub-surface deposits in the Adelaide Basin which indicate an extension to Southern Australia of Indo-Pacific conditions in Upper Middle Miocene and Lower Pliocene times.

The work upon which the writer has been engaged in recent years has involved investigation of foraminiferal faunas of Tertiary deposits not only in Australia but in New Guinea, Papua, Timor, Java and Sumatra. With the discovery of Indo-Pacific assemblages in the sediments in the Adelaide Basin, time seems opportune to consider some observations that have been made and to attempt a correlation of the Australian deposits with those in the Indo-Pacific Region.

Perhaps the most striking observation is the very large area over which the same foraminiferal assemblages and even the rock types are to be found in the Region. The area extends from Japan south through the Philippines and Sumatra, east through Java, the smaller islands of the Netherlands East Indies, New Guinea, Papua, the Solomons and New Hebrides, and north to islands such as Guam. From Timor it extends south to north-western Australia, and from there across southern Western Australia to South Australia and north-western Victoria.

Early in these investigations it was realised that eastern Australian Tertiary and Recent faunas were very slightly influenced by the climatic and bathymetric conditions that prevailed in the Indo-Pacific Region from Tertiary times onward, and it is intended in this paper to indicate the limits of such influence, as indicated by the distribution of the larger foraminifera.

The sources from which information regarding the distribution of the larger foraminifera in the Australian Tertiaries has been drawn, are rock collections which have been made during reconnaissance surveys by geologists attached to various companies in their search for oil in the North-West Basin of Western Australia, and by geologists of the Commonwealth Bureau of Mineral Resources from the Nullarbor Plains and Eucla sections in Western and South Australia, as well as samples from bores which have been drilled for water in the Adelaide metropolitan area by the South Australian Department of Mines, and in the Mallee and Wimmera areas in north-western and central western Victoria by the State Rivers and Water Supply Commission.

II. PUBLISHED AND UNPUBLISHED SOURCES OF INFORMATION

Little published work is available on the problem of the stratigraphic position of the Tertiary foraminiferal rocks in Australia and their relationship with Indo-Pacific stratigraphy.

Howchin (889) recorded *Lepidocyclina* under the name of *Orbitolites* from the limestones at Clifton Bank near Hamilton, Victoria.

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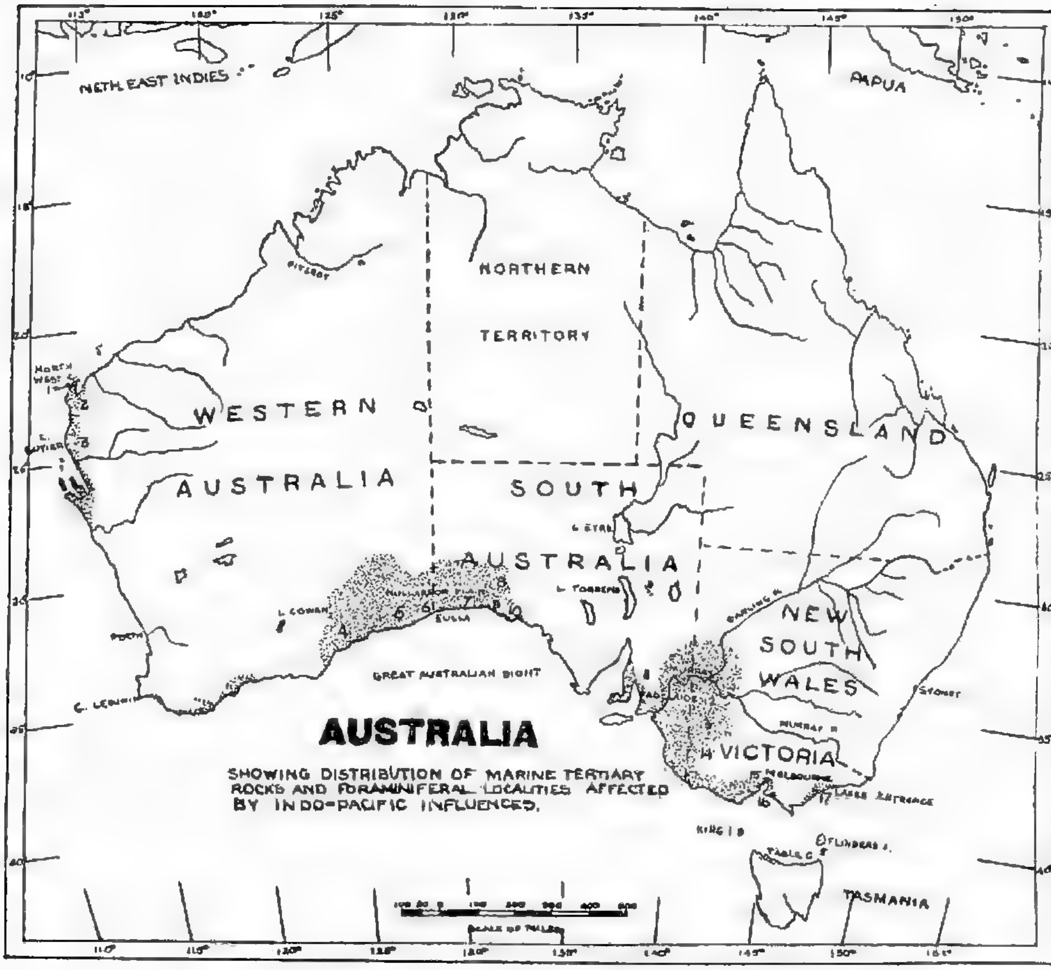
[1] Published by permission of the Director of the Bureau of Mineral Resources, Geology and Geophysics, Department of Supply and Development. Based on a paper read before Section C of the A.N.Z.A.A.S. Perth, August 1947.



Chapman (1910), in his study of the Batesford limestone, referred the *Lepidocyclinae* to European species, and Crespin (1926) listed *Ledipocyclina* from a limestone at Green Gully, near Keilor, Victoria.

The first record of larger foraminifera in north-west Australia was made by Chapman (1927), when he determined *Lepidocyclina dilatata* in a limestone submitted to him by F. G. Clapp from Exmouth Gulf. Later, in 1935, Chapman and Crespin determined Eocene foraminifera from rocks from the Giralia-Bullara area, North-West Division, Western Australia, collected by Messrs. Rudd and Condit. Species of *Discocyclina, Asterocyclina* and *Pellatispira* were recorded. In 1932 these two workers described *Lepidocyclinae* from bores in the Tertiary rocks of Victoria and suggested a correlation (based on the determination of *Spiroclypeus* in a limestone from Hamilton) of these deposits with "Stage e" in Java. Crespin later (1936) considered the specimen to be a section of a test of *Lepidocyclina.*

Raggatt (1936) included a short account based on departmental reports by Chapman and Crespin, of the Tertiary rocks of the North-West Basin, Western Australia, in his geology of the area.

In a report to the Australian and New Zealand Association for the Advancement of Science in Auckland (1937), the writer summarised the occurrences of Tertiary marine rocks in north-west Australia and indicated their relationships with Indo-Pacific types, and at the same time Chapman reported on the discovery of Eocene rocks in that area.

Crespin (1936) discussed the larger foraminifera in the Tertiary rocks of Victoria which were referred to the Lower Miocene, and suggested that the sub-genus *Lepidocyclina* indicated a younger age for the beds. Later, in 1941 and 1942, she made detailed studies of the genera *Cycloclypeus* and *Lepidocyclina* respectively in the Tertiary of Victoria and indicated their position in the Indo-Pacific stratigraphy. The subject was discussed further in her work on the Tertiary deposits of Gippsland, Victoria (1943).

Glaessner (1943) brought up to date the various lines of thought regarding Indo-Pacific Tertiary stratigraphy in his "Problems of Stratigraphic Correlation in the Indo-Pacific Region." Australia received little attention by Glaessner because of lack of published work.

Information on the foraminiferal assemblages in South Australian Tertiary deposits was derived from Howchin and Parr's study of the foraminifera in the metropolitan Abattoirs Bore, Adelaide (1938), and from Howchin's work on other bores in 1935 and 1936. Chapman's report (1916) on the Mallee Bores in Victoria formed the basis for work in that area and in the Wimmera.

Considerable evidence has been derived from unpublished departmental palaeontological reports since 1934, and these may be discussed under two headings: (a) North-West Basin, Western Australia, and (b) Southern Western Australia, South Australia and north-western Victoria.

(a) North-West Basin, Western Australia

Information has been derived from rock collections made by geologists during reconnaissance surveys for various companies engaged in the search for oil.

In 1934 D. Dale Condit and E. A. Rudd, on behalf of Oil Search Ltd., investigated the Exmouth Gulf area and collected limestones containing typical Eocene and Miocene Indo-Pacific foraminifera. H. G. Raggatt carried out further work for Oil Search Ltd in this area in 1934, and in 1935 he was accompanied by Washington Gray of the Commonwealth Oil Refineries Ltd. Both geologists made large collections of fossiliferous material. In 1936 E. A. Rudd made a further reconnaissance of the Exmouth Gulf area for Oil Search Ltd. and extended his survey down to the coastal section at Red Bluff and Cape Cuvier, and in 1941 geologists attached to Caltex (Australia) Oil Development, visited the Exmouth Gulf area and made collections from sections in Rough Range and Cape Range area.

(b) Southern Western Australia, South Australia and North-western Victoria

The greater part of the information on this region has been derived from bores drilled for water in South Australia and north-western Victoria, and from collections of fossiliferous limestones made by geologists of the Bureau of Mineral Resources, Canberra, and students of the University of Adelaide. The State Rivers and Water Supply Commission of Victoria has lately been drilling for water in the Wimmera, and since 1908 has had a drilling programme in the Mallee.

In 1944, H. B. Owen of the Bureau of Mineral Resources accompanied a party of geophysicists of the same organisation on a trip along the coastline of the Great Australian Bight from Port Lincoln in South Australia to Eyre in

Western Australia, and then across to Booanya and Balladonia. Owen collected from all available limestone outcrops between Ceduna and Norseman and made geological observations in this Tertiary Basin.

Last year Mr. King, a student of the Department of Geology, University of Adelaide, explored caves on the Nullarbor Plains and collected rocks from various localities in the vicinity of the caves.

Limestones have also been examined by the writer from Cook and Ooldea on the Transcontinental Railway.

III. METHOD OF CORRELATION OF TERTIARY MARINE ROCKS IN THE INDO-PACIFIC REGION

The basis of correlation of the Tertiary marine rocks in the Indo-Pacific Region is the distribution of the larger foraminifera in them. Dutch palaeontologists found it difficult to recognise some of the European stages in the Indo-Pacific, and in 1927 Van der Vlerk and Umbgrove instituted a "letter" classification. Since that time a considerable amount of detailed work has been carried out on the Tertiary faunas in the Netherlands East Indies by Dutch palaeontologists in collaboration with field geologists, with the result that a convenient classification was put forward by the late Dr. Tan Sin Hok in 1939, and this can be applied readily to those Tertiary rocks in Australia which come under the influence of Indo-Pacific conditions at the time of deposition. Tan's scheme, which has been modified by Glaessner (1943), is as follows:

Neogene - - - -	Upper Neogene (formerly "g" - "h") Upper Middle Neogene ("f_3") Lower Middle Neogene ("f_1" - "f_2") (Lower Neogene (Aquitanian, "e", included in Miocene)
Palaeogene - - - -	Oligocene ("c" - "d", distinguishable from Aquitanian only if reticulate Nummulites present) Eocene ("a" - "b")

This scheme is further modified in its application to Australia. It is considered that the following close approximations can be made—the Lower Neogene to the Lower Miocene, the Middle Neogene to the Middle to Upper Miocene, and the Upper Neogene to the Pliocene.

Characteristic larger foraminifera for the stages are:

Pliocene - - - -	Absence of larger zonal foraminifera
Upper Miocene ("f_3") - -	*Trybliolepidina rutteni*
Middle Miocene ("f_1" - "f_2")	*Nephrolepidina, Miogypsina, Flosculinella, Cycloclypeus, Austrotrillina*
Lower Miocene ("e") - -	*Eulepidina, Spiroclypeus, Neoalveolina*
Oligocene ("c" - "d") - -	*Eulepidina* and reticulate *Nummulites*
Eocene ("a" - "b") - -	*Assilina, Nummulites, Pellatispira, Discocyclina, Asterocyclina, Actinocyclina*

Rocks containing typical Eocene ("a" - "b"), Oligocene ("c" - "d") and Lower Miocene ("e") larger foraminifera are found only in north-western Australia. Zonal foraminifera of "f stage" are widely distributed not only in rocks in the North-West Basin but on the Nullarbor Plains and in the Eucla Basin, and in bores in the Adelaide Plains and north-western Victoria. Typical "f_3" rocks

with *Trybliolepidina rutteni* have not yet been found. Pliocene deposits probably equivalent to "g" occur along the north-western coast, on the Nullarbor Plains, and in the Adelaide Basin.

IV. APPLICATION OF THE "LETTER" CLASSIFICATION TO AUSTRALIAN MARINE TERTIARY DEPOSITS

Localities from which typical zonal foraminifera of the Indo-Pacific Region have been recorded in Australia are listed in Table I, which also gives the stratigraphic position of the various deposits.

A. Eocene ("a" - "b")

The only localities in Australia from which "a"-"b" foraminifera have been recorded are Giralia and Bullara south of the head of Exmouth Gulf, and at Red Bluff and Cape Cuvier in the coastal section south of the Exmouth Gulf area in the North-West Basin, Western Australia. Species of *Discocyclina, Asterocyclina, Actinocyclina, Pellatispira* and *Nummulites* have been determined. The exact position of these beds in the Eocene stratigraphic sequence is uncertain. *Pellatispira* and *Discocyclina* disappear at the top of the Eocene.

B. Oligocene ("c" - "d")

Definite Oligocene limestones are also restricted to the North West Basin of Western Australia. Large species of *Eulepidina* (*E. dilatata, E. papuaensis*) large *Cycloclypeus* (*C. eidae*) and small reticulate nummulites occur in the limestones from the base of an open gorge north of Mount King, Cape Range, and from the base of the section at Badjirrajirra Creek (north fork) 4·7 miles from its mouth on the Exmouth Gulf side of Cape Range. Chapman recorded *E. dilatata* from Exmouth limestones in 1927. He described *E. papuaensis* from a limestone at Bootless Inlet, Papua (1914), which contained small nummulites (*N. intermedia*) and which is now considered to be of Oligocene age.

C. Lower Miocene ("e")

Similarly, limestones containing typical Lower Miocene zonal foraminifera have not been found south of the North-West Basin. *Eulepidines* typical of stage "e" (*E. insulaenatalis, E. papuaensis*) are present in limestone 22 miles south of Yardie Creek Station, Cape Range. Other zonal forms, *Spiroclypeus tidoeganensis* and *Neoalveolina pygmaea*, together with small *Nephrolepidina* occur in rocks from Rough Range near Exmouth Gulf Homestead. *Eulepindina, Spiroclypeus* and *Neoalveolina* are not known to range above the top of "stage e".

D. Middle to Upper Miocene ("f")

Rocks of "stage f" are widely distributed in the North-West Basin and occur as far south as the section across southern Australia from Booanya and Balladonia in Western Australia to Colona east of the head of the Great Australian Bight in South Australia, thence to near Adelaide and across to north-western Victoria. No typical "f_3" rocks have been found. It is more satisfactory to subdivide the "stage f" rocks in Australia into "$f_1 - f_2$" and "$f_2 - f_3$". Probably some of the limestones in the Badjirrajirra Creek section may be referable to "f_1", but "f_3" has not yet been recorded.

"$f_1 - f_2$" rocks contain two assemblages of zonal foraminifera:

(2) An upper one with *Nephrolepidina* with some species showing *Trybliolepidina* tendencies, *Flosculinella*, *Cycloclypeus* and *Miogypsina*.

(1) A lower one with *Nephrolepidina* and *Cycloclypeus*.

Limestones containing Assemblage 1 occur in the Badjirrajirra Creek section, *Cycloclypeus* being the dominant form. This rock may be referable to "f_1". Well preserved specimens of the echinoid *Conoclypeus* were found in these beds.

Assemblage 2 shows an intermingling of typical "f_1" and "f_2" species and is fairly widely distributed in limestones in the Cape Range and Rough Range sections.

"$f_2 - f_3$" rocks have a wide distribution in Australia, and two assemblages of foraminifera are recognisable in them:

(1) Without *Lepidocyclina* but with *Austrotrillina, Flosculinella, Marginopora, Valvulina, Sorites, Peneroplis* and Miliolidae,

(2) With *Lepidocyclina,* also *Flosculinella, Marginopora* and Miliolidae.

It is possible that these two assemblages are equivalent in age, the absence of *Lepidocyclina* in Assemblage 1 being due to change in facies rather than difference in age.

Assemblage 2 is recorded from only two localities, one at Exmouth Gulf Station Outcamp in Rough Range, and the other near Yardie Creek Homestead, Cape Range in the North-West Basin. The assemblage is well known in the limestones in New Guinea and Papua and in parts of the Netherlands East Indies.

Assemblage 1 occurs in rocks in widely separated areas, from the North-West Basin, Western Australia, through the Nullarbor Plains to South Australia, thence to north-western Victoria, the same rock type ocurring from North-West Basin to the Nullarbor Plains. The limestone is cryptocrystalline, the foraminifera tests usually being stained black. The assemblage occurs in friable limestones in bores in the Adelaide Plains and in the Mallee and Wimmera in north-western Victoria.

Rocks containing Indo-Pacific Pliocene assemblages are not common in the Australian Tertiaries. Some of the coralline limestones in the Yardie Creek area, North-West Basin, have been placed in the Pliocene but no foraminifera are available to confirm this.

The limestones near Minilya Station, North-West Basin, contain *Marginopora, Sorites, Peneroplis* and *Valvulina* and in the absence of zonal Miocene forms are referred to the Pliocene. An identical rock, both in lithology and faunal content, occurs at Ooldea on the Nullarbor Plains and in the vicinity of Weebabbie Caves near Eucla. Numerous casts of molluscan shells, referable to species recorded from the Adelaide Plains deposits are present in the rock.

In the vicinity of Adelaide, extensive fossiliferous deposits known as the "Adelaidean" underlie the Adelaide Plains and outcrop at Hallett's Cove, at Christie's Beach, Port Noarlunga and at Aldinga. The foraminifera genera *Marginopora, Sorites, Peneroplis* and *Valvulina* form a characteristic assemblage, but the occurrence of zonal species of the Kalimnan stage of Victoria indicate a Lower Pliocene age for the beds.

V. COMMENTS ON THE INDO-PACIFIC ZONAL FORAMINIFERA IN AUSTRALIAN TERTIARY DEPOSITS

The zonal foraminifera in the Eocene ("a - b"), Oligocene ("c - d") and Lower Miocene ("e") rocks call for little comment. All species that have been determined are characteristic of the deposits of these ages throughout the Indo-Pacific, from Japan, the Philippines, Netherlands East Indies, New Guinea, Papua and north-western Australia, but are not known from southern Australia. However, in the Middle to Upper Miocene rocks which do extend to southern Australia, several species of zonal importance throughout the Indo-Pacific not only occur there but were described from the area.

The most important zonal form used in the correlation of "f stage" rocks is *Lepidocyclina* with its two subgenera *Nephrolepidina* and *Trybliolepidina.* The genus is found in the North-West Basin of Western Australia, but has not yet been recorded from limestones on the Nullarbor Plains nor in the vicinity of Adelaide and north-western Victoria, but it does occur in western, central southern and south-eastern Victoria. The subgenera *Nephrolepidina* is the zonal form for "f_1 - f_2" beds and it has not been recorded south of Cape Cuvier. Similarly, *Miogypsina,* which is characteristic of the "f_1 - f_2" assemblage, has not been found south of the North-West Basin.

In "f_2 - f_3" beds, *Nephrolepidina* gradually gives way to *Trybliolepidina,* which is very common at this horizon in the Indo-Pacific. On the Nullarbor Plains, from Boonya in Western Australia to Colona in South Australia, thence to the Adelaide Bores and Mallee and Wimmera Bores, *Trybliolepidina* is replaced by an assemblage in which the most important zonal form is *Austrotrillina howchini.* The associated zonal genus *Flosculinella* does not occur east of Colona.

Austrotrillina howchini, of such importance in "f stage" foraminiferal faunas in the Indo-Pacific, was described by Schlumberger (1893) from *Lepidocyclina* limestones at Clifton Bank, near Hamilton, western Victoria. The species has been recorded from "e stage" but has its greatest development in "f stage". The age of the beds from which *A. howchini* was described has been based on the *Lepidocyclina* population, which is dominated by the subgenus *Trybliolepidina* and which is regarded as the equivalent of "f_2 - f_3", and somewhere about the boundary of the Burdigalian and Vindobonian of the European stages (Crespin, 1942). Records indicate that *A. howchini* has not been found in the Indo-Pacific Region outside Australia in rocks younger than "f_3".

Other species which have been described from the Victorian *Lepidocyclina* limestones and which are found as far north as the North-West Basin in Western Australia, are *Gypsina howchini, Planorbulinella plana,* and *P. inaequilateralis.* Two other zonal species, *Crespinella umbonifera* and *Calcarina verriculata,* were described from bores in the Adelaide Basin from the *Austrotrillina howchini* horizon (Howchin and Parr, 1938). *C. verriculata* is very common in the *Lepidocyclina* limestones at Batesford. Both species are found in the North-West Basin.

An interesting assemblage of recent warm water genera, *Marginopora, Sorites, Peneroplis,* Miliolidae, occurs in the "f_2 - f_3" rocks and in the Pliocene in that portion of the Australian Tertiaries which have been subjected to Indo-Pacific influences at the time of deposition. This assemblage is found in rocks of topmost Miocene to Recent age throughout the Indo-Pacific, age being determined by the presence of zonal foraminifera. It is associated with *Austrotrillina* in "f_2 - f_3" limestones at Cape Cuvier in north-western Australia, in some of the limestones on the Nullarbor Plains, and in bores in the Adelaide Plains and in the Mallee and Wimmera. *Marginopora* rarely occurs in association with *Lepidocyclina,* due apparently to the fondness of the former genus for quiet tropical waters such as are found in the proximity of coral reefs. *Lepidocyclina* is usually associated with bryozoa which thrive where currents are present. The *Marginopora-Sorites-Peneroplis*-Miliolidae assemblage occurs with zonal Lower Pliocene (Kalimnan) species in the "Adelaidean" of the Adelaide Basin.

VI. POSITION OF THE MIDDLE TO UPPER MIOCENE AND PLIOCENE DEPOSITS OF SOUTHERN VICTORIA IN THE INDO-PACIFIC "LETTER" CLASSIFICATION

Broadly speaking, the majority of the bryozoal limestones in the Tertiary deposits of southern Victoria can be correlated with "f_2 - f_3" stage", based on

the presence of *Trybliolepidina* in the upper portion of the section. The writer, in her investigations on the genera *Lepidocyclina* and *Cycloclypeus* in Victoria (1941, 1942), showed that the subgenus to which the *Lepidocyclina* belonged was *Trybliolepidina*, and that the species of these two genera were different from those in known Indo-Pacific deposits. She suggested that this difference in species was due to "the presence of an embayment in south-eastern Australia in which other species, but still with Indo-Pacific affinities, flourished." Glaessner (1943) sums up the problem in the following statement: "Faunal relations between the surprisingly uniform Tertiary of the Indo-Pacific Region and that of south-eastern Australia and New Zealand are limited and are either created by "eurythermic" species which were able to cross the boundary of the tropical belt or by short-lived climatic or ecologic changes, creating a suitable environment for warm-water species and genera. In the Tertiary of Victoria the Batesfordian, containing a group of *Lepidocyclina* as well as *Austrotrillina* and perhaps some other Indo-Pacific smaller foraminifera, forms a short-lived link with the Indo-Pacific Region."

Although *Austrotrillina howchini* was described from the *Lepidocyclina* limestone at Clifton Bank near Hamilton, it is not a common form in the *Lepidocyclina* deposits in southern Victoria. It does not occur in the rich *Lepidocyclina* limestones at Batesford and Flinders in the central southern portion, nor in Brock's Quarry and in the numerous bores from which the *Lepidocyclina* horizon has been recorded in Gippsland, but it does occur sparingly in that horizon at Skinner's section, Mitchell River, near Bairnsdale, Gippsland. The species is well represented in the portion of the Mallee Bores which have been subjected to Indo-Pacific influence and where it is associated with *Marginopora*. The typical Indo-Pacific genera *Miogypsina* and *Flosculinella* have not been recorded from Victoria.

The Middle Miocene bryozoal limestones of south-eastern South Australia and western Victoria contain no large zonal foraminifera, but some of the limestones are correlated with the "$f_2 - f_3$" beds of Victoria by means of smaller zonal species which are associated with the larger forms in the *Lepidocyclina* limestones.

No zonal Indo-Pacific foraminifera are known from the Victorian Lower Pliocene—referred to as the Kalimnan—which suggests unsuitable ecologic conditions during Pliocene times in Victoria. According to present knowledge, suitable conditions did not extend eastward beyond the vicinity of Adelaide.

VII. SUMMARY

1. Indo-Pacific influence in faunal assemblages in Australian Tertiary rocks extends from North-West Basin, Western Australia, to southern Western Australia, across the Nullarbor Plains to South Australia and north-western Victoria.

2. Correlation of the marine Tertiaries of Australia with occurrences elsewhere in the Indo-Pacific Region is made by means of the larger foraminifera, which form the basis of the letter classification instituted by Dutch palaeontologists in their work in the Netherlands East Indies.

3. Eocene ("a - b"), Oligocene ("c - d") and Lower Miocene ("e") rocks containing typical zonal foraminifera are not recorded south of the North-West Basin, Western Australia.

4. Middle to Upper Miocene ("f") zonal foraminifera are widely distributed in limestones in southern Western Australia, across the Nullarbor Plains, in the vicinity of Adelaide and in north-western Victoria. Even similar rock types have been recognised.

5. No larger zonal foraminifera of age value are present in the rocks of Pliocene age, local zonal species being age determinants. But associated with the local species are well-known Indo-Pacific recent forms. Rocks containing such assemblages occur in the North-West Basin, at Ooldea on the Nullarbor Plains and in the Adelaide Bore sections and in the coastal sections south of Adelaide, where they are referred to as the "Adelaidean" and are Lower Pliocene.

6. The *Lepidocyclina* limestones of Victoria, which are considered to be equivalent to "$f_2 - f_3$" stage indicate a short-lived link with the Indo-Pacific. The genus *Lepidocyclina,* which is represented by the subgenus *Trybliolepidina,* shows Indo-Pacific affinities, but the species are distinct.

7. The conclusion drawn from the above observations is that Indo-Pacific conditions extended down the coast of Western Australia, across the southern part of the State into South Australia and north-western Victoria in Middle Miocene to early Upper Miocene ("$f_2 - f_3$") time, with a very limited extension into southern Victoria. Then followed a gradual recession of conditions. No Pliocene deposits containing Indo-Pacific forms are known east of the Adelaide Plains and the sections south of Adelaide along Gulf St. Vincent. According to Cotton, of the South Australian Museum, the examination of molluscan faunas in South Australia suggests that this recession has continued westwards during Pleistocene and Recent times.

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TABLE 1

Correlation of Australian Tertiary Localities Based on Indo-Pacific Foraminiferal Assemblages

Age	Letter Classification of Dutch Palaeontologists	Zonal Foraminifera	North-West Basin, Western Australia	Nullarbor Plains, Booanya, W.A., To Colona, S.A.	Adelaide Basin, S.A.	Mallee and Wimmera, North-Western Victoria
Lower Pliocene	? "g"	*Marginopora* *Sorites* *Valvulina* *Peneroplis* (absence of zonal Miocene forms)	11 miles N.W. of Minilya-Waroora boundary on coast road. Minilya Station ¾ m. W. of Gerardi Bore. Minilya Station 3.25 m. S.E. of Chirrita Minilya Station 3.25 m. S.E. of Chirrita Bore. Minilya Station shallow well on track between Chirrita and Gerardi Bores. Yardie Creek, W. of Cape Range.	Ooldea Surface near Weebabbie Caves	Adelaide Bores "Adelaidean" Hallett Cove Christie's Beach Pt. Noarlunga Aldinga Section	—
	"f 3"	*Trybliolepidina rutteni*	—	—	—	—
Upper Miocene to Middle Miocene	"f 3" to "f 2"	(without *Lepidocyclina*) *Austrotrillina* *Flosculinella* *Calcarina* *Crespinella* *Marginopora* *Valvulina* Miliolidae	E. flank, Giralia anticline where Bullara track crosses first low hills. Approx. crest Chargoo Dome ¾ m. from Minilya-Waroora boundary fence. Limestone Range on Waroora road 4.5 m. N.W. of Waroora road crossing of Lyndon River on main coast road from Minilya. Trealla Hills, Cape Range, S. end of Chargoo Anticline. Cape Cuvier, Coastal Section. Gully ¼ m. N. of Red Bluff, Coastal Section.	Booanya Balladonia Madura Top of Eucla Section White Wells Outstation Colona	*Adelaide Bores* Bore No. 65 (600′–620′) Bore No. 58 (208′-311′) Nathan Brewery (500′–524′) Kinnish Direk No. 1 (280′–318′) Kinnish Direk No. 2 (265′–365′)	*Mallee Bores* Nos. 2, 4, 9, 11 (near Murrayville) Ph. Ballarang, Allot. 28. Campbell's Bore Ph. Tunart (387′-406′) *Wimmera Bores* Dimboola No. 1 (80′–131′)
		Lepidocyclina (chiefly *Trybliolepidina*) *Flosculinella* *Marginopora* Miliolidae	Yardie Creek Homestead, Cape Range. Exmouth Gulf outcamp Rough Range.	—	—	—
	"f 2" to "f 1"	*Nephrolepidina* *Flosculinella* *Miogypsina* *Cycloclypeus*	Gorge W. of outcamp Exmouth Gulf Station, Rough Range. Open gorge N. of Mt. King, Cape Range (top of section). E. of Yardie Creek Homestead, Cape Range. Bed of Creek, 3.5 m. from Bullara on road to Giralia, S. of head of Exmouth Gulf. Portion of Badjirrajirra Creek Section, Cape Range.	—	—	—
Lower Miocene	"e"	*Eulepidina* *Neoalveolina* *Spiroclypeus* *Miogypsinoides* *Cycloclypeus*	Rough Range, near Exmouth Gulf Station Homestead. 22 m. S. of Yardie Creek, Cape Range. W. end of Cape Range, Yardie Creek Station. Gorge N. of Exmouth Gulf Station outcamp, Rough Range.	—	—	—
Oligocene	"c"—"d"	*Eulepidina* with reticulate *Nummulites*	Open gorge, N. of Mt. King, Cape Range (base of Section). Badjirrajirra Creek 4.7 m. from mouth, Cape Range.	—	—	—
Eocene	"a"—"b"	*Nummulites* *Discocyclina* *Pellatispira* *Actinocyclina* *Asterocyclina*	Bed of Creek at track crossing 8.5—9 m. from Bullara on road to Giralia, S. of head of Exmouth Gulf. 10.5 m. from Bullara on road to Giralia. E. flank of Giralia anticline where track to Bullara crosses the first low hills. Red Bluff Section most southerly exposure of yellow limestone, Cape Cuvier.	—	—	—

THE MARINE ALGAE OF KANGAROO ISLAND
II. THE PENNINGTON BAY REGION

By H. B. S. Womersley

Summary

The first paper of this series (Womersley 1947) gave a general description of the algal ecology of Kangaroo Island, together with an account of the more important environmental factors for the island as a whole, and a discussion of the terminology found most satisfactory in describing the algal ecology.

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II. THE PENNINGTON BAY REGION

By H. B. S. Womersley*

[Read 8 July 1948]

Contents

* Department of Botany, University of Adelaide.

INTRODUCTION

The first paper of this series (Womersley 1947) gave a general description of the algal ecology of Kangaroo Island, together with an account of the more important environmental factors for the island as a whole, and a discussion of the terminology found most satisfactory in describing the algal ecology.

This paper deals with one of the distinctive regions of the Kangaroo Island coast, *viz.*, the horizontal rock platforms of the Pennington Bay region and other areas of the south coast of the island (see previous paper). The Pennington Bay reefs, because of their easy accessibility from the American River settlement, have been studied in some detail. The same type of rock platform has been briefly examined elsewhere along the coast—east of Vivonne Bay and at Sou'-West River—and their algal ecology appears to be similar in all cases. This is in accordance with the similarity in structure of the reefs and in the environmental conditions to which organisms inhabiting them are subject.

These rock-platform reefs are classed as a distinct section of the Exposed Rocky-coast Subformation around Kangaroo Island (Womersley 1947). They are formed by wave action from consolidated calcareous sand-dunes of Recent to Pleistocene age, and alternate with areas of Precambrian rocks along the south coast.

Pennington Bay is not well defined. The western part of the bay is formed of cliffs 80 to 100 feet high overlying Precambrian rocks. In the central and eastern parts the sand-rock cliffs are lower, usually less than 50 feet high, forming small outcrops and headlands, separated by sandy beaches backed by sand-dunes (see pl. X). Further to the east the cliffs are more continuous and tend to be higher.

From the cliff bases stretch out the horizontal wave-cut platforms, composed of the same calcareous sand rock as the cliffs. Except in a few cases where wave action has eroded small caves at the cliff base, the cliffs descend almost vertically to the flat reef surface. Rock above high water level is usually sharply pitted and ridged, that on the reef itself less so but still forming a hard and rough surface.

The characteristic feature of the reefs is their flat, horizontal surface and vertical drop off at the edge into deep water of 10 to 20 feet. Many reefs are undercut in varying degrees, with occasional tunnels and blow holes up through the reef surface.

The following account is based largely on the reefs occurring along some 1½ miles of coast at Pennington Bay and to the east. The Precambrian rocks which form the western headland of the bay are not included in the discussion. The most accessible reef is also one of the largest. It is situated some 100 yards west of the track to Pennington Bay from the American River – Hog Bay road, and almost due south from a large sand hill known as Mount Thisbe. This reef illustrates well the main features of the reefs generally, and most of the algal associations found in the region occur on it. The distribution of the algal associations on this "main reef" (pl. XI, fig. 1) will be used as a basis for the following descriptions, reference being made where necessary to other reefs.

Almost the whole surface of these rock platforms is dominated by algae, though molluscs and other animals are characteristic of many associations. In the rear littoral, on sloping and more exposed rock, several animal associations occur, often pure but sometimes co-dominant with algae in restricted areas. It has proved most satisfactory to deal with the algal associations by themselves, although mention is made in cases where algal-animal biocenoses occur. A full account of the fauna of the Pennington Bay reefs is given by Edmonds (Edmonds 1948).

ENVIRONMENTAL CONDITIONS

A general account of the environmental conditions of the Kangaroo Island coast has been given previously (Womersley 1947). The more important environmental factors at Pennington Bay are summarised below.

Tidal Range—Spring range, 2½ feet approximately; neap range, 1½ feet approximately. The effect of wind and the state of the sea greatly modify the tidal rise, often causing low or high water when least expected.

Roughness—Conditions on outer parts of the reefs are always rough, becoming calmer further in as breakers passing over the reefs gradually lose their force. Breakers are a constant feature of the Pennington Bay coastline, but with a north wind and calm sea they are only 1 to 2 feet high (pl. X and XI). Such conditions, however, are not common, and with a heavy swell breakers up to 8 or 10 feet high occur off the reefs (pl. IX, fig. 1, pt. I).(1) During calm conditions and a low tide, most of the reefs may be exposed, or have few waves passing over them. High summer air temperatures may kill or damage large reef algae under such conditions.

At the rear of the reefs conditions are usually much calmer, but most areas of sloping rock are washed over by small waves, and pools of still water occur only at low tide.

Temperature—The following table of sea temperatures on the main reef gives some idea of the yearly range. All figures are isolated readings, but the daily or weekly variation is small owing to deep water close in shore.

Table I

Sea temperatures on the main reef, Pennington Bay

	Jan.	April	May	June	July	Sept.	Nov.
Temp. °C. - -	19·0	18·5	17·5	16·0	13·5	14·0	16·0

Temperatures on the main reef are usually within 1° C. of the sea temperature off the reef (warmer in summer, warmer or cooler in winter depending on the air temperature). On rock platforms above the reef surface, and usually above high water level, isolated pools may occur where water temperatures reach 30° C. during summer. Such pools bear a characteristic but sparse algal community (see later).

The yearly range in sea temperature is small (about 5·5° C.), but variation in size and seasonal occurrence of a number of reef algae can best be attributed to this.

Air temperatures—Few figures of air temperatures are available. Some for Kingscote (on the north coast of Kangaroo Island) have been given previously (Womersley 1947). The climate generally is insular and mild. Air temperatures of most importance in the algal ecology occur on hot summer days, when they may reach 37° C. If combined with a north wind and low tide exposing the

(1) Part I refers to the first paper of this series (Womersley 1947).

reef surface, this may result in considerable damage to reef algae, particularly species of *Cystophora* and *Hormosira banksii* (which occurs on higher levels of the reefs). No harmful effect of exposure during low tides in winter months has been observed, nor would be expected as air temperatures are not often higher than sea temperatures from June to September.

Winds—Southerly to westerly winds are most frequent on the south coast of Kangaroo Island. Easterlies often occur, but occasional northerlies during hot summer weather are the only winds of direct importance in the algal ecology (see under Temperatures).

Chlorinity—Isolated readings (January 1946) have given a chlorinity of $19 \cdot 5$-$19 \cdot 6\,^0/_{00}$ (salinity $35 \cdot 2$-$35 \cdot 4\,^0/_{00}$) for water on the reefs. Little annual change would be expected. Isolated pools above the reef surface are often more saline, particularly in summer (chlorinity $20 \cdot 5$-$22 \cdot 2\,^0/_{00}$), and usually lower after heavy rain.

Alkalinity—Colorimetric methods have given a pH of 8·2 to 8·3 for water on the reef.

ZONATION

The relatively small tides, and constant breakers, result in no marked horizontal zones such as described by numerous workers in regions of greater tidal range. Algal zonation does occur, however, and differences in reef levels of only 2 or 3 inches frequently cause profound changes in the algal associations (see reef section, fig. 1). The greatly dissected nature of the coastline, and the variety and grading of the habitats on the reefs, tend to obscure any obvious zonation, but over the whole area of the coastline examined there occur numerous well-marked associations, characterised by fairly distinct environmental conditions.

The average horizontal level of the reefs seems to correspond fairly closely to a mean low tide level (neaps). Some areas, either on the outer edge or elsewhere on the reefs, are a few inches higher than the rest, while shallow channels and pools often occur on the reef surface. Such features are well shown on the main reef (see map and pl. XI, fig. 1).

The reef surface is therefore classed as being in the *littoral zone*.[1] However, owing to the form of the reefs, few of the algae on their flat surface are ever completely exposed; many occur in shallow pools or areas of water retained on the reef at low tide. In other slightly higher areas the growth is so dense that a considerable amount of water is retained in the masses, and such areas are washed over by occasional waves. Only at the rear of the reefs on sloping and vertical rock which is classed as the *rear littoral* are the algae exposed for any length of time at low tide (see reef section, fig. 1).

The algal associations grouped together in the littoral zone are therefore subject to a much smaller degree of exposure than are littoral associations on steeply sloping rock in calmer seas. This is a characteristic feature of horizontal rock platforms wherever they occur, in contrast to the conditions on steeply sloping coasts. Algal ecological literature contains very few accounts of similar rock platforms, which are however a distinctive feature of many parts of the southern Australian coast.

The littoral zone is considered to include all algal associations at higher elevations, subject to wave action or spray. These may occur 2 or 3 feet above actual high tide level, but this is due entirely to the effect of wave splash and, in some areas, of shade.

(1) For discussion of terminology see Womersley 1947.

The only algal community which can truly be classed at *supralittoral* is one of *Prasiola,* which is found only where penguin colonies occur. This habitat is also subject to fine, blown spray, but is more semi-terrestrial than marine. At least one mollusc association can be best considered as supralittoral (Edmonds, this journal, p. 168).

The edge of the reef, and to 1 or 2 feet down the vertical side, is termed the sublittoral fringe (pl. XIV, fig. 4). A very distinctive association of algae occurs on this part of the reefs. The importance of the sublittoral fringe zone in the broad algal ecology of Kangaroo Island has been outlined in the first paper of this series.

Below the edge of the reef, for at least 3 or 4 feet down (as far as it is possible to investigate), zonation occurs, but the deeper sublittoral flora is known only from the assemblage found cast up and not growing on the reefs. Dredging off the shore is, unfortunately, quite impossible.

THE ALGAL ASSOCIATIONS

Description of the Main Reef

The shape and appearance of the main reef at Pennington Bay is shown in pl. XI, fig. 1 and by the map. It measures some 70 yards across and 75 yards from beach to outer edge. Other reefs at Pennington Bay are shown in pl. IX, fig. 3, pt. I.

On the north-west corner of the main reef are cliffs about 15 feet high, with a ledge 2-3 feet wide at the base. This ledge forms the western side of a sandy pool, which is about 5 feet deep in the outer corner, and has a small sandy beach at the rear. The amount of sand on the beach and in the pool varies greatly at different times. As a general tendency the beach and pool are heavily sanded up in summer (pl. XIV, fig. 1), but with considerable bare rock in winter (pl. XII, fig. 3; also see map); this allows development of *Ectocarpus* and *Enteromorpha* associations on the exposed rock in winter. The amount of sand present, however, is largely dependant on the weather over the previous few weeks. The eastern part of the reef is backed by rocks which have fallen from the cliffs—the "fallen rock region" (pl. XII, fig. 1 and 2). At the north-east corner of the reef is a small rock platform which contains several rock pools on the top, about 5 feet above the reef surface.

A noticeable feature of the reef is the absence of loose rocks on the surface; a few which occur in the fallen rock region are almost dry at low tide and too large to be removed by wave action. This results in the virtual absence of the characteristic fauna, and to a lesser extent the flora, which inhabits the undersurface of loose rocks (see Pope 1943).

An important structural feature of the main reef is a ledge forming a drop of 6-12 inches, running in a curve through the centre of the reef to the south-east corner (pl. XI, fig. 1; pl. XIV, fig. 1 and 2, and map). This ledge, due to the almost continual streaming of water over it, even at low tide, bears a distinct algal association.

The areas colonised densely by *Hormosira* on the outer part of the reefs are slightly higher than the rest. Between the main area of *Hormosira* and the ledge is a shallow channel, 6 to 10 inches below the eastern part of the reef, which widens out towards the sandy pool. Except at an extremely low tide there is some water movement along this channel. A less well defined channel passes in from the outside edge of the reef between the two main areas of *Hormosira.* The western side of the reef is fairly even and 6 to 12 inches lower than the eastern half.

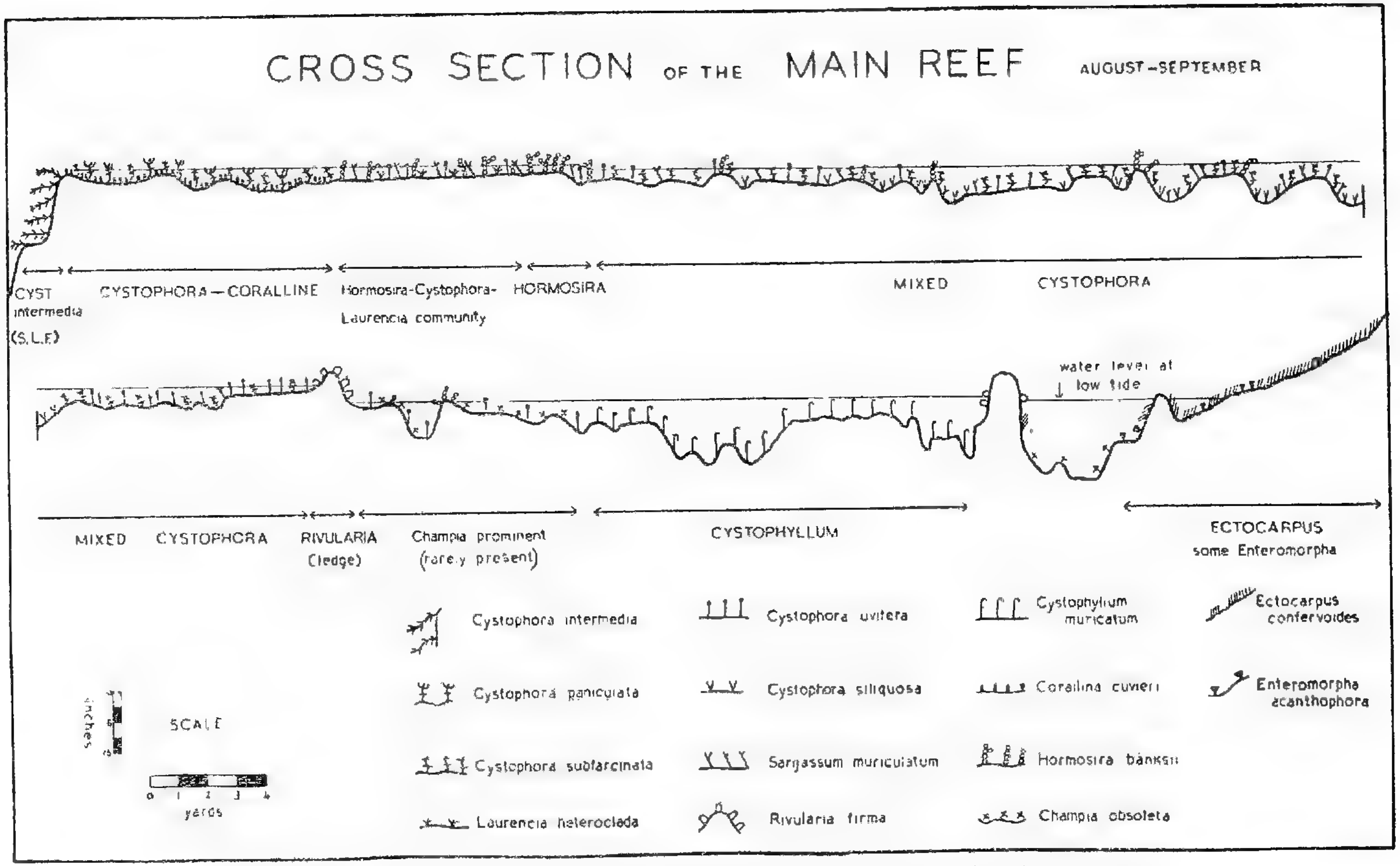


Fig. 1 Cross section of the main reef, Pennington Bay. For direction and position, see map.

The outer edge of the main reef is greatly dissected, with numerous pools and pot-holes (pl. XV, fig. 3). This is the roughest area of the reef and bears the dense and distinctive sublittoral fringe association. The south-eastern corner is more even, but slightly higher, with a greater degree of exposure between waves. An association characterised by the articulated corallines, *Corallina* and *Jania*, together with species of *Cystophora*, is developed here.

Owing to the position of the shallow channel, and slightly higher eastern side of the reef, general water movement is across the reef to the western side where it streams off the reef. Very little debris is ever cast up at the rear of the main reef, but is deposited on beaches on either side.

The main reef has been described in some detail because it illustrates well the manner in which slight differences in height of the reef (sometimes only 2 or 3 inches), and the degree of roughness in different parts, control the occurrence and distribution of the algal associations (pl. XIII, fig. 2). This will be evident in discussing the associations, and also from the cross section of the reef shown in fig. 1. The map shows the distribution of algal associations on the main reef during January (full map), and during August-September 1946 (inset). These illustrate the summer and winter appearances of the main reef, but owing to the varying amounts of sand covering parts of the rear littoral in winter months, the distribution of rear littoral associations often differs from that shown for August-September 1946.

At the western end of Pennington Bay, near the headland of Precambrian rock, is a reef formed of three or four horizontal terraces, each 1 to 2 feet vertically above the next and sloping steeply between each (pl. XI, fig. 2). The sand rock of this reef is the same as elsewhere in the bay, and there seems no obvious reason for the development of such a distinctive and different type of reef.

This "western terraced reef" bears several algal-animal communities which are absent or poorly developed on the typical rock platforms. The *Hormosira – Ectocarpus / Pylaiella* – anemone community will be referred to later, and a very prominent *Modiolus* (mollusc) association is described by Edmonds. An association of stunted *Laurencia heteroclada* occurs at a low littoral level.

The following account of the algal associations of the Pennington Bay region is based largely on their distribution on the main reef. Reference is made where necessary to their distribution on other reefs elsewhere in the Pennington Bay region and also in Vivonne Bay, but the main reef has proved to be very typical of this type of reef generally.

The Supralittoral Zone

Over most of the coast no algae are found in the supralittoral zone, but in restricted areas two poorly developed algal communities occur, and also a sparse lichen community.

Prasiola community

Prasiola sp. occurs on rock or stones on sloping parts of the cliffs up to 25 feet above high water, but only where well developed penguin tracks pass up these cliffs. One such locality is about ½ mile east of the main reef. The community is not prominent, and of infrequent occurrence. The alga, which is undetermined specifically, forms small green patches, rarely more than 2 or 3 cm. across, of tangled cylindrical filaments. Its habitat is subject to fine blown spray in considerable amount, but it is best regarded as a semi-terrestrial alga rather than a marine one. *Prasiola* is best developed during the winter months.

The other two communities described below are not strictly supralittoral but occur at a level above the main littoral communities, and are described here as a matter of convenience.

LICHINA COMMUNITY

Small black patches of the lichen *Lichina confinis* (Muell.) Ag. occasionally occur in sheltered areas in the fallen rock region of the main reef, and in similar habitats along most of the coast. On the south coast of Kangaroo Island it rarely forms a distinct association, but is much more prominent and covers considerable areas of rock in calmer areas on the north coast. It occurs at least partly above high tide level, its distribution being controlled by wave splash and shade.

ISOLATED ROCK-POOL COMMUNITY

On the small elevated platform at the north-east corner of the main reef (see map) occur several isolated pools. These pools are about 4½ feet above the reef surface, and are subject to wave splash only under rough conditions. Similar pools situated above high tide level occur infrequently in the Pennington Bay region. Owing to their small size, habitat conditions in the pools are extreme; on hot summer days water temperatures may reach 35° C., falling to 20° C. or less at night; while winter temperatures are often lower than the sea temperature. Salinity conditions are also variable.

The flora of these pools is sparse and variable in its occurrence, but characteristic of the habitat. It is usually better developed during the winter. The following species are most frequent: *Polysiphonia abscissa* H. & H., *P. frutex* Harv., *P. dasyoides* Zan., *Laurencia heteroclada* Harv., *Ectocarpus confervoides* (Roth.) Le Jol. (winter), *Ceramium miniatum* Suhr. and *Centroceras clavulatum* Ag. All are species of wide habitat range, and in many cases they are common in littoral associations.

THE LITTORAL ZONE

The associations of this zone are conveniently divided into those occurring on sloping rock at the rear of the reefs, and those on the flat reef surface. Those in the rear littoral are more tolerant of exposure than the reef surface forms, and except at high tide are exposed between each wave. The distribution of the associations on the main reef during summer (January) and winter (August-September) is shown in the map. The cross section of the reef during September (fig. 1) shows the vertical relationships of the associations between the shore and the outside edge of the reef.

Rear littoral associations

1. SYMPLOCA HYDNOIDES ASSOCIATION

Symploca hydnoides Kütz., a filamentous blue-green alga, forms dark, felt-like irregular patches, to 3 or 4 cm. across, on sloping and vertical rock at the rear of the reefs. At high tide it is washed or splashed by each wave, but may be left exposed for several hours at low tide. The soft spongy mats of the alga retain water strongly. The height to which *Symploca* reaches is controlled by the amount of wave splash, varying from 1 to 4 or 5 feet above the reef surface. It is best developed in shaded areas.

Although at times this association is very inconspicuous, *Symploca hydnoides* occurs on rock bare of other algae. It is found in similar habitats on rock-platforms elsewhere along the south coast of Kangaroo Island.

On one shaded rock in the fallen-rock region of the main reef a biocenose of *Symploca hydnoides* and the barnacle *Tetraclita purpurascens* occurs.

2. Gelidium pusillum association

This association at Pennington Bay is but a poor example of the *Gelidium pusillum* (Stackh.) Le Jol. association on calmer coasts, such as at Rocky Point or in the American River inlet. Conditions at Pennington Bay are mostly too rough, and it is restricted to thin patches on vertical and sloping rock in locally sheltered places. On the main reef the cliff above the ledge forming the sandy pool has thin scattered patches in shaded hollows; it also occurs in the fallen rock region, mainly on the sides of the rocks.

On exposed rock, *Gelidium pusillum* forms yellowish brown much branched thalli, but when growing in pools the fronds are upright, less branched, and 1 to 3 cm. high.

Like *Symploca*, this is not a conspicuous association, but it is of general occurrence in similar habitats on the sandrock reefs. In some areas it is co-dominant with the serpulid worm *Galeolaria caespitosa* in a biocenose.

3. Rivularia firma association

Rivularia firma Womersley forms dark blue-green gelatinous blobs up to 2 cm. across (masses to 4 or 5 cm. across) in parts of the rear littoral where there is constant wave splash, or on ledges over which waves stream. Such habitats were exposed between waves at low tide, but only for very short periods. A high degree of aeration seems to be of most importance. The firm gelatinous thalli can resist considerable exposure during the occasional very low tide and hot summer weather.

Rivularia firma occurs along the south and west coasts of Kangaroo Island, in the upper littoral, whatever the type of rock. The association varies greatly in its development from place to place, for no obvious reason. At Pennington Bay rocks in the rear littoral may be densely covered with the hemispherical blobs (pl. X, fig. 2, pt. 1), with no other algae present; in other places, and at different times, the rock may be bare. Development is usually better during winter months, and may be very poor in summer.

On the main reef, the ledge running in a curve through the centre of the reef to the south-east corner is usually dominated by *Rivularia firma*. This is a region of constantly streaming, broken water, and is colonised by a distinctive group of algae. Apart from *R. firma*, the commonest are *Hydrocoleum glutinosum* (Ag.) Gomont, *Rivularia atra* Roth., *Polysiphonia frutex* (epiphytised by *Calothrix confervicola* (Roth.) (Ag.), *Hormosira banksii* Dcne., *Laurencia heteroclada*, with scattered plants of *Wrangelia plumosa* Harv., and *Champia obsoleta* Harv. The dominance of blue-green algae on this ledge is striking, but similar ledges have not been found elsewhere in Pennington Bay, though they may occur.

On the small "islands" on the ledge (see map) and in more exposed parts of this association, *Galeolaria caespitosa* often becomes co-dominant with the *Rivularia*.

4. Ectocarpus confervoides and Pylaiella fulvescens seasonal associations

Ectocarpus confervoides and *Pylaiella* (*Bachelotia*) *fulvescens* Bornet occur in the same habitat on sloping rock in the lower rear littoral, or sometimes in pools in a similar position, at different times of the year. *Ectocarpus* occurs during winter months (April to November), *Pylaiella* during the summer (September to May). Both species grow on sloping, well washed rock which is exposed between waves at low tide (fig. 1; pl. XII, fig. 3 and 4, and map). They reach their greatest size (to 7 or 8 cm. high) however where always covered, with

slight wave action. During summer the sloping rock at the rear of the sandy pool (main reef) is usually buried under sand, preventing *Pylaiella* from developing there.

In appearance both algae are very similar, forming brown tufts, but whereas *Ectocarpus* is abundantly branched, *Pylaiella fulvescens* is branched only at the base and the tufts are less distinct.

Scytosiphon lomentarius (Lyngb.) J. Ag. is frequently found in both associations, especially in winter when it is heavily epiphytised by *Ectocarpus confervoides*.

5. Enteromorpha acanthophora association

Enteromorpha acanthophora Kütz. forms a striking and pure association in the rear littoral of the Pennington Bay reefs, in very much the same habitat as *Ectocarpus* and *Pylaiella*. Both associations however are remarkably distinct, with rarely any intermixing. Why this is so is not clear, for rock on the same slope and subject to apparently identical conditions may be covered by two quite distinct areas of *Ectocarpus* and *Enteromorpha*. The association varies considerably in its development from time to time, being best developed in late winter. Small scattered plants occur in the inner channel area from time to time.

Both the *Enteromorpha* and *Ectocarpus–Pylaiella* associations occur where loose sand is carried about by the waves. The algae appear to be very tolerant to this sand movement, and may even survive short periods of burial in sand.

6. Ulva lactuca association

Ulva lactuca L. (f. *rigida* (Ag.) Le Jol.) often colonises areas slightly lower than *Enteromorpha*, and scattered plants occur at the rear of many reefs. The habitat is less exposed than that of *Enteromorpha*. The plants are variable in form, from broad expanded sheets to elongate undulate ribbons, and rarely more than 12 cm. high.

Littoral associations

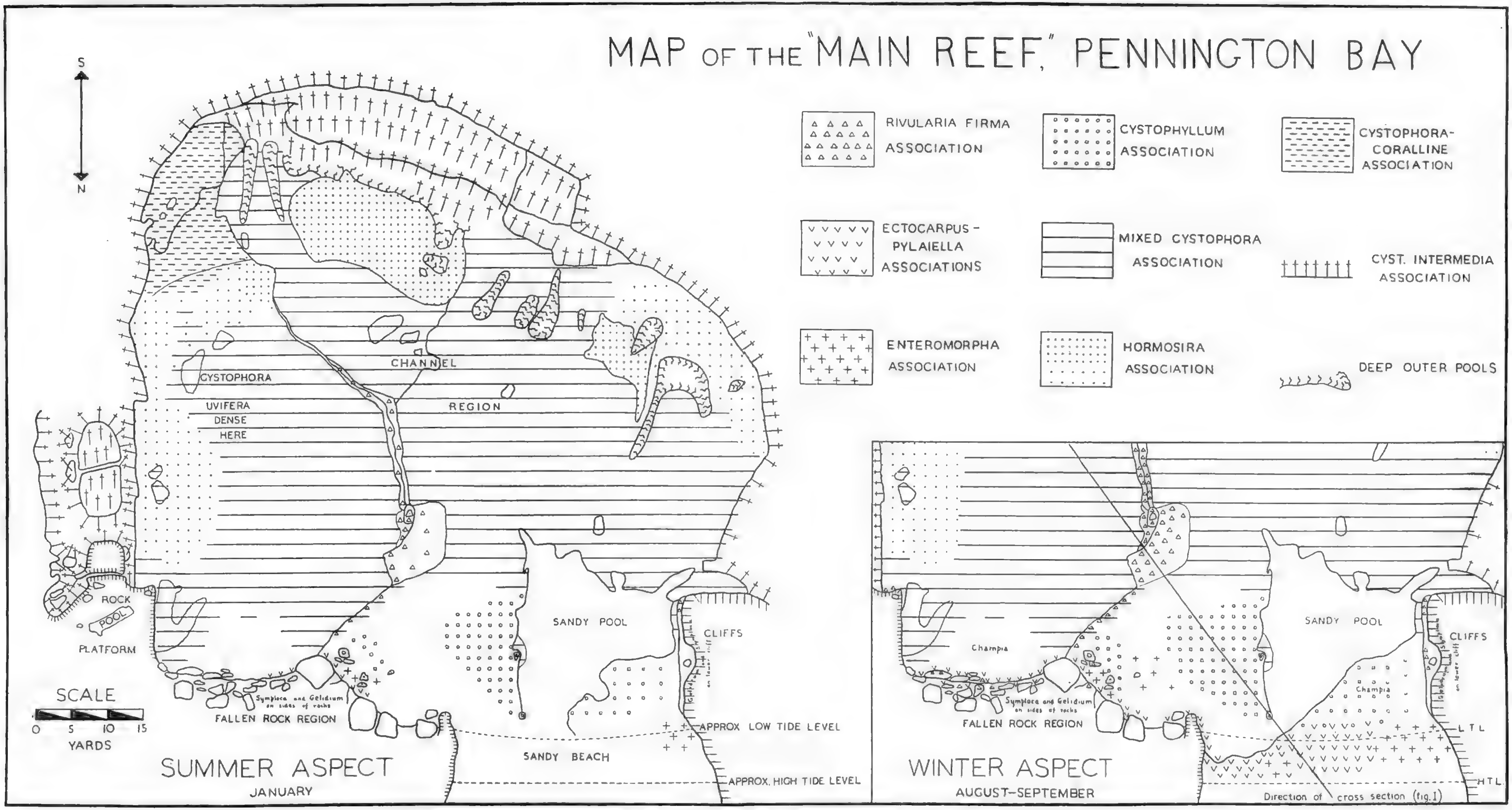
The associations described below as being in the littoral zone are not strictly so, as most of the algae are rarely exposed for any length of time. At low tide many of the larger species reach the water surface, and others are covered by only a few inches of water. A few, such as *Hormosira*, are exposed at every low tide. On calmer coasts *Cystophora subfarcinata*, *C. siliquosa* and often *C. brownii* are characteristic of the upper sublittoral, but with the exception of *C. siliquosa* few of the reef algae extend into the sublittoral. From most viewpoints it is convenient to regard the following associations as characteristic of the littoral zone.

7. Polysiphonia frutex association

Polysiphonia frutex is common throughout the year on the ledge and calmer areas of the main reef. On other reefs at Pennington Bay, including one immediately west of the main reef, it forms a pure association on flat or sloping rock in areas of medium to slight wave action. The alga reaches a height of only 5 to 7 cm., but is dense enough to give the area a dark brown appearance. Common epiphytes are *Polysiphonia abscissa* and *Calothrix confervicola*.

8. Cystophyllum muricatum association

The area between the sandy pool and the ledge on the main reef (see map) is covered by a pure association of *Cystophyllum muricatum* (Turn.) J. Ag. Other algae are virtually absent from this area. *Cystophyllum* also occurs as scattered plants on rock in the sandy pool and near the fallen rock region. On other reefs it is not common, but usually pure when it does occur.


MAP OF THE "MAIN REEF," PENNINGTON BAY
S
N
RIVULARIA FIRMA ASSOCIATION
CYSTOPHYLLUM ASSOCIATION
CYSTOPHORA-CORALLINE ASSOCIATION
ECTOCARPUS - PYLAIELLA ASSOCIATIONS
MIXED CYSTOPHORA ASSOCIATION
CYST. INTERMEDIA ASSOCIATION
ENTEROMORPHA ASSOCIATION
HORMOSIRA ASSOCIATION
DEEP OUTER POOLS
CHANNEL
REGION
CYSTOPHORA
UVIFERA
DENSE
HERE
ROCK
POOL
PLATFORM
SCALE
0 5 10 15
YARDS
Symploca and Gelidium on sides of rocks
FALLEN ROCK REGION
SANDY POOL
CLIFFS
APPROX LOW TIDE LEVEL
SANDY BEACH
APPROX. HIGH TIDE LEVEL
SUMMER ASPECT
JANUARY
Champia
SANDY POOL
CLIFFS
Champia
Symploca and Gelidium on sides of rocks
FALLEN ROCK REGION
L T L
H T L
WINTER ASPECT
AUGUST–SEPTEMBER
Direction of cross section (fig. 1)

The alga reaches a height of 20 cm., developing best at the edges of slightly deeper pools. *Sphacelaria biradiata* Asken. and *Sphacelaria furcigera* Kütz. are common epiphytes on the lower stems during summer. Occasionally the plants are almost buried in sand, but appear to suffer little damage. The association is always, but only just, submerged.

The rocky bottom in the north-eastern half of the sandy pool is rarely covered by sand, and bears a very mixed assemblage of species. At low tide it is covered by 1-3 feet of water, with fairly calm conditions. *Cystophyllum muricatum* is present here, though not well developed and in varying amounts throughout the year. Other species may be prominent at different times, developing rapidly and disappearing after two or three months. Such species are *Liagora harveyana* Zeh., *Helminthora tumens* J. Ag.? *Champia obsoleta* (winter), *Dictyopteris acrostichoides* (J. Ag.) Schmitz? *Ectocarpus confervoides* and *Scytosiphon lomentarius* (both winter), *Pylaiella fulvescens* (summer), *Muellerena* sp. (winter), with *Ulva lactuca* and *Enteromorpha acanthophora* in the shallower parts. This mixed group of species is also found on the eastern part of the main reef, in shallower water near the fallen rock region, but is less well developed here. Most of the species are found in other associations on the reef.

9. Jania fastigiata association

On several reefs in the Pennington Bay region (one immediately east of the main reef) and also on reefs in Vivonne Bay, *Jania fastigiata* Harv. colonises otherwise bare rock in the littoral zone. The association is not a dense one, but distinctive in appearance. The fronds (to 4 or 5 cm. high) are bleached white in summer, but in many cases are heavily epiphytised by *Calothrix confervicola*, giving the association a blackish-green appearance. The habitat is usually of fairly even rock, just exposed at very low tides.

10. Laurencia heteroclada association

Laurencia heteroclada occurs as a minor component of several reef associations, and is widely distributed along the south coast of Kangaroo Island. On the lower level of the western terraced reef (pl. XI, fig. 2), and similar sloping rock in the low littoral, it forms a community which is doubtfully of association rank. The alga grows as a dense turf, up to 7 cm. high, yellowish-brown in colour, of stunted plants where it is subject to fairly heavy wave action. This habitat is rarely exposed, being only slightly higher than the sublittoral fringe. A stunted *Sargassum*, *Cladostephus verticillatus* (Lightf.) Ag., *Caulerpa brownii* Endl., *C. simpliciuscula* Ag., and *Chaetomorpha darwinii* Kütz. often occur with it.

11. The Cystophora complex

The greater part of most of the Pennington Bay reefs is colonised by species of *Cystophora*. Their extent on the main reef is shown by the map. The mixed *Cystophora* association covers the area east of the ledge, consisting of numerous shallow pools retaining 4 to 10 inches of water at low tide, and also the channel area and most of the western part of the reef.

Four species of *Cystophora*, *C. uvifera* (Ag.) J. Ag., *C. subfarcinata* (Mert.) J. Ag., *C. siliquosa* J. Ag. and to a lesser extent *C. brownii* (Turn.) J. Ag., together with *Sargassum muriculatum* J. Ag., form a complex of associations. Depending on small variations in depth of water and calmness, each may form an almost pure association, or, as is more common, a mixed association of almost any combination of two or more species (pl. X, fig. 1, pt. 1). The shallow pool area east of the ledge on the main reef is dominated by *Cystophora subfarcinata*, *C. siliquosa* and *C. uvifera*, with some *Sargassum muriculatum*. This is referred to as a "mixed *Cystophora* association". As pure associations,

C. subfarcinata and *C. siliquosa* are most frequent.

The importance of *Cystophora* in the algal ecology of Kangaroo Island is in many ways analagous to the importance of Eucalypts in South Australian land ecology. In the previous paper it was shown that the algal formations and subformations around Kangaroo Island can be characterised by the presence or absence of species of *Cystophora*. Of some 25 species in the genus, 17 occur around Kangaroo Island.

(a) *Cystophora uvifera* forms a pure association on flatter and calmer parts of the reefs. On the main reef it dominates an area of more even rock running outwards towards the south-east corner, and also parts near the western edge (pl. XIV, fig. 3). It is densest where just covered at low tide, partly due to insufficient depth of water at low tide to allow other (and larger) species of *Cystophora* to develop.

C. uvifera forms short, rather stunted plants, to 25 cm. high, with one to several stems arising from the base. It shows remarkable seasonal variation in vesicle production, which seems to be attributable only to seasonal variation in sea temperature (a range of about 5·5° C. on the reef). *C. uvifera* has always been described as bearing spherical mutic vesicles on the main stem (Harvey Phyc. Aus., pl. 175). This is the form found in calmer waters or rarely cast up from the sublittoral. On the Pennington Bay reefs, vesicles have never been found on the plants during January. By May, small elongate vesicles with a strongly developed mucro occur in small numbers on most plants. These approach closely the vesicles of *C. cephalornithos*, which is only found in much calmer habitats. In September vesicles are numerous, the older ones being almost spherical and with only a small mucro. The "typical" mutic vesicles are rarely seen, and by mid-summer the vesicles are lost. It seems evident that besides the controlling effect of temperature in vesicle formation, the relatively rough conditions on the Pennington Bay reefs cause the juvenile forms of vesicle (elongated and mucronate) to be largely retained.

Sargassum muriculatum is commonly present in the same area as *C. uvifera*. *Sphacelaria furcigera*, and occasionally *Sph. biradiata*, grow epiphytically on the stems.

(b) *Cystophora subfarcinata*—This alga grows in slightly deeper water than *C. uvifera*, where wave action is greater but not extreme. Apart from *Hormosira banksii*, it is the most widespread species on the reefs. On the main reef it is one of the dominants of the mixed *Cystophora* association, and is particularly prominent in pools more than 6 inches deep and in the channel area, where it is always in 6 to 12 inches of water (pl. XIV, fig. 3).

Cystophora subfarcinata never produces vesicles on the Pennington Bay reefs, or elsewhere on the south coast. In sheltered parts of the north coast, however, vesicle formation is common. This is a clear case of ecological forms under different degrees of wave action.

(c) *Cystophora siliquosa* inhabits deeper pools than *C. subfarcinata*. It forms a characteristic fringe around most of the deeper rock pools towards the outside of the reef, and also on the western side of the reef where water streams off. It cannot survive strong direct wave action. Small plants occur over most of the mixed *Cystophora* association on the main reef, but only in deeper rock pools does it attain its maximum length of 5 or 6 feet. Near the western edge of the reef, *Antithamnion hanowioides* (Sond.) De Toni, *Antithamnion* sp. and *Dasya* spp. are common epiphytes on *C. siliquosa*.

On other reefs, and rock off the edges of reefs, *C. siliquosa* forms a pure association in 2 to 5 or more feet of water.

(d) *Cystophora brownii*—This species is less common than the previous three, and does not occur on the main reef. On reefs east of Pennington Bay it is sometimes codominant with *C. subfarcinata* in 1-2 feet of water (at low tide) towards the rear. Only rarely has it been seen pure.

(e) *Sargassum muriculatum*—This, the only important littoral species of *Sargassum*, is common on most of the rock platforms, and shows remarkable seasonal development. On the main reef it occurs near the fallen rock region, on flatter areas with *C. uvifera*, and in the channel, but is densest on the western side of the reef where it thrives in the constantly streaming water. In the latter area it is often dominant, but elsewhere is usually subdominant to the *Cystophora*.

During summer *Sargassum muriculatum* is a short stunted plant rarely more than 10 or 12 cm. high, and it can be easily distinguished from *Cystophora uvifera* only by its flattened stem. Growth commences during March or early April, and during winter the fertile fronds are developed, reaching a height of 40 or 45 cm. By September small vesicles, almost identical with those of *S. sonderi* J. Ag., are produced, but by early November the fruiting frond disintegrates, losing both receptacles and vesicles. The stalk of the old frond persists for some weeks, but by January the plants are reduced to a short stem bearing a few branches with crowded, almost terete leaves (such as figured by Agardh [1889]). This striking seasonal development must be due to lower water temperatures, though the annual range, as given previously, is small.

Throughout the *Cystophora* associations scattered plants of *Hormosira banksii* may occur chiefly on higher ridges (pl. X, fig. 1, pt. 1). Tiny dark blue-green thalli of *Rivularia atra* are also common on bare rock in the association. An intermediate community between the mixed *Cystophora* and *Hormosira* associations on the main reef will be discussed later.

Several other algae occur irregularly in the *Cystophora* complex, varying greatly in their distribution and occurrence in different seasons. These will be dealt with later under "Chance distribution of minor species" (see p. 157).

Although the species of *Cystophora* are the largest algae growing on the reefs, much of the rock between the plants is left bare. This is probably due in some measure to removal of young plants of other species by the fronds of the *Cystophora* as the latter are moved over the rock by waves. On one occasion (April, 1947) the channel area had been almost denuded of algae, only the holdfasts remaining. Growth of new plants in this area was poor, and it would seem that few species apart from those of *Cystophora* grow readily in areas of shallow streaming water. Yet such a habitat appears to be just as suitable as many where algal growth is heavy, such as the sublittoral fringe association. When compared with the latter association the *Cystophora* complex is poor in number of species, though composed of larger plants.

12. Hormosira banksii association.

Hormosira banksii (f. *sieberi* [Bory] Dcne.) is more widespread than any other alga on the Pennington Bay reefs. It occurs from the outer edge to the inner calmer areas, but only on higher parts of the reefs in fairly rough conditions does it form a dense and distinct association. On two areas on the outside of the channel on the main reef, and a smaller area just east of the ledge near the *Cystophora*-coralline association (see map), it becomes very dense, to the exclusion of all other algae except a few epiphytes (pl. XIII, fig. 2 and 3). The areas of pure *Hormosira* are only a few inches above the rest of the reef, but are exposed between waves at low tide, sometimes for several minutes. On many reefs the *Hormosira* association is near the outer edge or sides. Many reefs have the surfaces markedly ridged, and bear *Hormosira* only on the ridges where it is exposed at low tide (pl. XIII, fig. 1).

The chains of bead-like vesicles (about 1 cm. across) of *Hormosira* provide an abundant reservoir of water for the alga to tolerate exposure and desiccation. No other alga has a similar structure, so it is not surprising that *Hormosira* alone can colonise these higher areas. The abundance of the plants in the pure areas, and their large size compared with the same species elsewhere on the reef, would indicate however that some degree of exposure is beneficial to the growth of *Hormosira*.

On the rare occasions of a hot north wind and very low tide, leaving the reef exposed for some hours, *Hormosira* on higher areas may suffer considerable damage, becoming black and withered.

Notheia anomala is a very common parasite, growing from the conceptacles. Other epiphytes are the black tufts of *Polysiphonia nigrita* Sonder, and *Hydrocoleum lyngbyaceum* Kütz. which forms small dark blue-green furry growths in the constrictions between the vesicles.

The second level of the western terraced reef (pl. XI, fig. 2) comprises numerous pools, 3 to 6 feet across and up to 1 foot deep. Waves enter the pools at medium and high tides. *Hormosira banksii* forms a dense fringe around the edges, and well-developed plants occur on the bottom, usually reaching to the surface (pl. XIII, fig. 4). Also on the bottom of the pools occur brown tufts of the filamentous species *Polysiphonia abscissa*, *Ectocarpus confervoides* (winter) and *Pylaiella fulvescens* (summer). The red anemone *Actinia tenebrosa* is prominent in shaded hollows around the edges of the pools, just below and for a few inches above the water line.

The development of this *Hormosira-Actinia* biocenose is due essentially to the specialised habitat—shallow pools exposed at low tides and subject to wave influx at higher tides. From the algal viewpoint it is best considered as a variant of the typical *Hormosira* association and has been seen only on the western terraced reef.

13. Cystophora – coralline association

The south-east corner of the main reef receives the full force of breakers, though on the eastern side waves tend to surge over and along the edge. This corner is slightly higher than most of the reef, and bears a closed and dense association (pl. XV, fig. 1). On higher, but rough and constantly wave-swept parts of other reefs the same association is prominent.

Dominant are the dark brown, densely branched fronds of *Cystophora paniculata* (Turn.) J. Ag., often stunted lighter-brown fronds of *C. subfarcinata*, and two species of the articulated coralline algae. Small tufts and mats of *Corallina cuvieri* Lamx. cover most of the rock between the larger algae, while *Jania fastigiata* Harv. is heavily epiphytic on *C. subfarcinata* (pl. XV, fig. 1 and 2). During winter *Corallina cuvieri* (f. *crispata* Lamx.) is a pale pink, while *Jania* is a brighter red. In summer both are bleached to a faint pink or white, but on all occasions the contrast of the brown fronds of *Cystophora* and the pink or white of the corallines gives the association a distinctive appearance (pl. XV, fig. 1 and 2).

Cystophora paniculata is well developed in the rough areas but absent from the rest of the reef. Though usually abundant, on occasion it has been almost absent (September 1946). On some reefs it is rare and the association is dominated by the corallines.

The degree of epiphytism in this association is very high. Most species can grow on either rock or the *Cystophora*. The rough warted stem of *C. paniculata* provides an excellent substrate for many species. Some epiphytes are seasonal in their occurrence.

Species present throughout the year include: *Dasyopsis clavigera* Womersley, *Polysiphonia nigrita*, *P. dasyoides*, *Heterosiphonia gunniana* (Harv.) Falk., *Chaetomorpha darwinii*, *Caulerpa brownii*, *C. simpliciuscula*, *Laurencia heteroclada* and *Antithamnion hanowioides*. Less common ones are *Zonaria subarticulata* (Lamx.) Papenfuss, *Pachydictyon paniculatum* J. Ag., *Sargassum bracteolosum* J. Ag., *S. muriculatum*, *Xiphophora chondrophylla* (R. Br.) Harv. (in pure but small patches), odd plants of *Hormosira banksii*, *Ceramium nobile* J. Ag., *C. miniatum*, *Wrangelia plumosa*, *Metagoniolithon charoides* (Lamx.) W. v. B. *Melobesia* sp. and *Calothrix confervicola*.

Monospora elongata (Harv.) De Toni and *Griffithsia monilis* Harv. are common epiphytes, forming bright red tufts, but they only occur during the winter (April to November). *Thuretia teres* Harv. and *Mychodea foliosa* (Harv.) J. Ag. are found mainly on the stems of *C. paniculata*.

Intermediate Communities

Intermediate and grading communities between the associations discussed above are not frequent, but as is expected on such reefs variations in height and exposure between different associations will result in a mixing of species. In addition, other species may be suited by the intermediate habitats yet not occur in either of the main associations.

On the main reef, rock to the east and south-east of the mixed *Cystophora* association bears a community dominated by *Hormosira banksii*, *Cystophora uvifera* and *Laurencia heteroclada* (which varies greatly in abundance during the year). *Sargassum muriculatum* also occurs. The change between this community and the *Cystophora*–coralline association takes place over 2 or 3 feet. It is essentially an intermediate community between the mixed *Cystophora* and *Hormosira* associations, under conditions which are suitable for *Laurencia heteroclada*. Near the eastern edge of the reef *Hormosira* becomes dominant.

The mixed and variable assemblage of species found in shallow areas near the fallen rock region and on rock in the sandy pool is described on page 153.

The *Hormosira*–anemone pool variant of the *Hormosira* association has been dealt with on p. 156. *Ectocarpus confervoides* and *Pylaiella fulvescens*, which are subdominant in this community, dominate seasonal associations in the rear littoral, while *Polysiphonia abscissa* is also characteristic of more isolated rock pools (see p. 150).

Chance Distribution of Minor Species on the Main Reef

A number of algae occur on the main reef, but do not form a stable component of any particular association. At different times during the year they may occur on widely separated areas of the reef, usually in relatively small patches within larger fairly uniform habitats. Chance establishment of the species under temporarily suitable conditions, rapid development of individual plants and relatively small spread from the original area, followed within a few months by death under changed conditions, seems to account for the observed distribution. The following species have attracted attention.

Liagora harveyana grew near the fallen rock region and the eastern edge of the reef in January 1946. In January 1948 it was prominent on rock in the sandy pool, while in November 1947 it was found only on the outer western part of the channel area. On other occasions it has been found confined to the ledge.

Helminthora tumens (?) is best developed in the late winter, occurring on inner parts of the reef. In September 1946 it was partly buried by sand in the rear littoral, where it was exposed between waves. At other times it has been confined

to the sandy pool (January 1948) and a small area on the western side of the channel (November 1947). Plants exposed and buffeted by waves are considerably stouter than those always covered.

Champia obsoleta, during September 1946, was so prominent in shallow inner areas of the reef that it could well be considered to dominate a community. At other times it has been confined to the ledge or eastern edge of the reef, but often is virtually absent from the reef surface.

Cladosiphon filum (Harv.) Kylin is often absent from the reef, but a few scattered plants may occur near the fallen rock region, and in November 1947 it was quite dense over a few square yards of the mixed *Cystophora* association in the channel.

Cladosiphon vermicularis (J. Ag.) Kylin has been found in outer pools on the main reef (November 1947), but is quite common in a cove west of the main reef.

Halopteris pseudospicata Sauv. and *Phlocecaulon spectabile* Reinke occur in pools in 2 or 3 feet of water, and occasionally on rock in the sandy pool.

Cladostephus verticillatus is only rarely found in pools on the main reef, but on the sides of rock in the lower littoral and upper sublittoral in other parts of Pennington Bay it may be quite dense.

Cladophora valonioides Sonder may occur as scattered plants almost anywhere on the reef, but usually only in a restricted area at any one time.

Flora of Shaded, Rear Littoral Pools

A number of reefs in the eastern part of the Pennington Bay region have small caves, up to 8 or 10 yards in length, at the base of the cliffs. At high tide waves usually enter them, and pools often occur at the entrance or just inside. Such pools are shaded, relatively calm, and contain an assemblage of algae of sublittoral affinities. The habitat is similar to sublittoral conditions in light and degree of roughness.

Algae most frequently found in these pools are *Apjohnia laetevirens* Harv (stunted), *Rhipiliopsis peltata* (J. Ag.) A. & E. S. Gepp, *Ecklonia radiata* (Turn.) J. Ag. (in larger pools), *Plocamium angustum* (J. Ag.) H. & H., *Phacelocarpus labillardieri* J. Ag., *Corallina cuvieri*, *Laurencia elata* (Ag.) Harv., *Haloplegma preissii* Sonder, *Spyridia opposita* Harv., *Ballia scoparia* Harv. In one small pool less than 2 feet long and 1 foot wide, under an overhanging rock in the fallen region of the main reef, the following small Chlorophyceae were found: *Rhipiliopsis peltata* (abundant), *Bryopsis baculifera* J. Ag., *Derbesia clavaeformis* (J. Ag.) De Toni, *Caulerpa* sp. and *Vaucheria* sp. These are all rare species at Pennington Bay.

Other sublittoral species probably occur in such pools on other parts of the south coast of Kangaroo Island.

The Sub-littoral Fringe Zone

Cystophora intermedia association

The sub-littoral fringe on the Pennington Bay reefs corresponds to the outer and side edges and a foot or so below (pl. XIV, fig. 4, and pl. XV, fig. 3). The outer edge of some reefs is probably a little above mean low water mark, and on other reefs slightly below, but the conditions at the reef edge are uniform as even at low tide waves are constantly breaking on it, leaving it almost or just exposed for a few seconds between waves. The outer edge is the roughest habitat on the reefs; the sides are less rough, but both are habitats of high aeration of the water, short but frequent exposure between breakers, and heavy forces from wave action.

The sublittoral fringe bears the densest algal association found anywhere on the reefs. The rock is usually completely covered, and epiphytic growth is profuse. In number of species the association is very rich. On an area of 4 or 5 square yards at the outside of the main reef over 50 species have been collected; most are small in size and often stunted, only the Fucales being of any bulk. The chief requisite of an alga in this association is a strongly developed holdfast. The masses of fronds, however, afford considerable protection for each plant, as wave forces can be exerted only from above and not from underneath the plants.

The association is dominated by *Cystophora intermedia* J. Ag. The dark brown pinnately branched fronds of this alga reach a length of 50 cm., and give a characteristic appearance to the reef edge (pl. XIV, fig. 4, and pl. XV, fig. 4). *C. intermedia* is remarkable for its inability to grow anywhere except in the roughest, well aerated places. No satisfactory explanation of this is available at present. Although its stems are only 3 or 4 mm. in diameter, they are extremely strong. A very heavy pull is needed to remove a well-developed plant, and only on extremely rare occasions has this alga been found cast up on the beach.

The algae of the sub-littoral fringe belong mainly to two types. The majority have elongate, often much divided fronds which offer minimum resistance to waves; others form mat-like masses on the rock which are also protected by larger bushier forms.

Where waves pass along the reef edge (eastern side of main reef), *C. intermedia* grows densely from the edge to 2 feet below. In situations where there is heavy wave splash, caused by projecting parts of the reef, it will grow on the surface; this is particularly so on the outer highly dissected part of the main reef and on the large rocks off the eastern edge. However, where water streams off the western side of the reef, and breakers are of reduced force, *C. siliquosa* replaces *C. intermedia* in the sublittoral fringe to a large extent.

Cystophora intermedia is often heavily epiphytised by other algae, which grow only from the conceptacles. The stem is too smooth and mucoid to provide a hold for algal spores. During summer the small brown blobs of *Corynophloea cystophorae* J. Ag. are common on the upper fronds, while a species of *Dasya* and *Crouania muelleri* Harv. occur in winter.

Other larger algae of the sublittoral fringe are *Sargassum bracteolosum* (with *Acrochaetium* sp. epiphytic on the leaves) (pl. XV, fig. 4) and occasional plants of *Ecklonia radiata*, *Scytothalia dorycarpa* (Turn.) Grev., *Cystophora spartioides* (Turn.) J. Ag., and *C. paniculata*; *C. subfarcinata* and *C. siliquosa* do not occur below the reef edge except in calmer places.

The following are the most important of the smaller species. Nearly all are stunted in size owing to the rough habitat, much larger forms being cast up from deeper water.

Caulerpa brownii, *C. sedoides* (R. Br.) Ag., *C. simpliciuscula*; *Codium pomoides* J. Ag., *Pachydictyon paniculatum*, *Lobospira bicuspidata* Aresch., *Dictyopteris acrostichoides* (?), *Gymnosorus variegatus* (Lamx.) J. Ag.; *Liagora harveyana*, *Gelidium australe* J. Ag., *Metagoniolithon charoides*, *Corallina cuvieri*, *Mychodea foliosa*, *Gigartina* sp., *Iridaea prolifera* (J. Ag.) De Toni (rare), *Champia obsoleta*, *Hymenocladia polymorpha* (Harv.) J. Ag. *H. conspersa* (Harv.) J. Ag. (juvenile state only), *Nemastoma feredayae* Harv., *Phylimophora imbricata*, J. Ag., *Sarcomenia dasyoides* Harv., *Ballia scoparia*, *Callithamnion laricinum* Harv., *Griffithsia antarctica* H. & H. *Haloplegma preissii*, *Wrangelia plumosa*, *Chondria* sp., *Laurencia heteroclada*, *L. robusta*,[2] *L. elata*

[2] M.S. name for an apparently undescribed species.

(with epiphytic *Janczewskia tasmanica* Falk.), *Jeannerettia lobata* H. & H. *Dasyopsis clavigera*, *Heterosiphonia gunniana*, *Thuretia teres.* In addition the following species are usually epiphytic on larger fucoids: *Ceramium nobile*, *Antithamnion hanowioides*, *Crouania Muelleri*, *Monospora elongata* and *Griffithsia monilis* (both only in winter months), *Muellerena insignis* (Harv.), De Toni, *Polysiphonia nigrita* and *P. dasyoides.*

The large rocks off the eastern edge of the main reef (see map, and pl. IX, fig. 2, pt. I) provide a habitat particularly favourable to *Laurencia*, *L. heteroclada*, *L. elata* and *L. robusta* occurring in abundance. *Antithamnion hanowioides* is often densely epiphytic on all three species. The bright green of *Caulerpa brownii* and *C. simpliciuscula* provides a striking contract amongst the deep red of the other species.

The Sublittoral Zone

Zonation below the sublittoral fringe

Study of zonation in the sublittoral is limited to 3 or 4 feet down the vertical sides of some reefs; even this can be observed only on very calm days with low tides. The following is, very broadly, the zonation down the eastern edge of the main reef.

To 2 feet below edge - -	*Cystophora intermedia*
From 1½-2½ feet below edge -	*Wrangelia clavigera* Harv., *Gelidium australe* and *Scytothalia dorycarpa*
From 2-3 feet below edge - -	*Perithalia inermis* (R. Br.) J. Ag., and usually below this *Plocamium costatum* (J. Ag.) H. & H. and *Phacelocarpus labillardieri*
	Laurencia elata may be prominent at about this level

Flora of deep outer pools on the reefs

Scattered over most of the Pennington Bay reefs, particularly on the outer parts (often within the sublittoral fringe—pl. XV, fig. 3), are rock pools up to 6 feet or more deep, with vertical or steeply sloping sides. The flora of these pools is always submerged and must therefore be considered sublittoral. Light intensity is lower in the pools than on the reef surface, especially for smaller species which are usually shaded by large fronds of *Cystophora* growing around the edge. Conditions within the pools are calmer than on the reef surface.

Around the edge *Cystophora siliquosa* is usually dominant. Here the fronds remain well submerged, and with ample room for their development often reach a length of 2 metres. *Sargassum bracteolosum*, and to a lesser extent *Scytothalia dorycarpa* and *Ecklonia radiata*, are common near the edge.

Apart from the fringing edge of *Cystophora*, the conspicuous feature of these pools is the bright green masses of *Caulerpa* which cover the sides in patches up to a foot or more across. *Caulerpa brownii*, *C. obcura* Sond., *C. hypnoides* (R. Br.) Ag. var. *muelleri* (Sond.) W. v. Bosse, *C. longifolia* Ag., *C. simpliciuscula*, *C. sedoides* and sometimes *C. scalpelliformis* (R. Br.) Ag. are found, best developed where shaded by other algae or the pool edge. The characteristic vegetative growth by means of surculi results in fairly pure patches of one species, but much of the rock is left bare.

Other species irregularly distributed in these pools are *Rhipiliopsis peltata*, *Dictyosphaeria sericea* Harv., *Apjohnia laetevirens* (often the basal part only), *Halopteris pseudospicata*, *Phloeocaulon spectabile*, *Cladosiphon vermicularis*, *Dictyopteris acrostichoides*, *Dilophus* sp. and *Gymnosorus variegatus*.

THE DEEPER SUBLITTORAL FLORA

The following list of species includes those found cast up but known not to grow on the reef surface. Other species in the list do grow in the littoral or sublittoral fringe zones, but are usually much larger when growing in the deeper sublittoral. All sublittoral species found in the Pennington Bay region are not listed here, but a complete census and notes on the species known from Kangaroo Island will be published as a later paper. The cast up species found at any one time depends greatly on the weather over the previous few days, and no reliable data as to the absence of a sublittoral species at any time can be obtained.

CHLOROPHYCEAE: *Codium galeatum* J. Ag. (common), *C. mamillosum* Harv., *C. spongiosum* Harv., *C. pomoides*, *Caulerpa harveyi* W. v. B., *Cau. obscura*, *Cau. hypnoides*, *Cau. ethelae* W. v. B., *Apjohnia laetevirens*, *Cladophora valonioides*.

PHAEOPHYCEAE: *Giraudya* sp. (on *Posidonia australis*); *Phloeocaulon spectabile*, *Halopteris pseudospicata* Sauv.; *Dictyota latifolia* J. Ag., *D. radicans* Harv., *Dictyopteris muelleri* (Sond.) Schmitz, *Dilophus fastigiatus* (Sond.) J. Ag., *Zonaria subarticulata* (syn. *Z. turneriana* J. Ag.), *Z. crenata* J. Ag., *Chlanidophora microphylla* (Harv.) J. Ag., *Homoeostrichus sinuosus* (R. Br.) J. Ag., *H. spiralis* J. Ag., *Lobospira bicuspidata*, *Sporochnus scoparius* Harv., *S. comosus* Ag., *Encyothalia cliftoni* Harv., *Bellotia eriophorum* Harv., *Polycerea zostericola* (Harv.) Kylin (?), *Nereia australis* Harv., *Myriodesma calophyllum* J. Ag., *M. integrifolia* Harv., *Sirococcus axillaris* Grev., *Carpoglossum confluens* (R. Br.) Kütz., *Scaberia agardhii* Grev. (very common), *Cystophora racemosa* Harv., *C. pectinata* (Grev. and Ag.) J. Ag., *C. platylobium* (Mert.) J. Ag., *C. retorta* (Mert.) J. Ag., *C. grevillei* (Ag.) J. Ag., *C. dumosa* J. Ag., *C. monilifera* J. Ag., *Sargassum bracteolosum*, *S. cristatum* J. Ag., *S. trichophyllum* J. Ag., *S. decipiens* (R. Br.) J. Ag., *S. sonderi* J. Ag., *S. varians* Sond.

RHODOPHYCEAE. Common: *Asparagopsis armata* Harv., *Delisea hypneoides* Harv., *Callophyllis lambertii* H. & H., *Areschougia laurencia* Harv., *Erythroclonium muelleri* Sond., *Hypnea episcopalis* H. and H., *Plocamium costatum*, *P. nidificum* (Harv.) J. Ag., *P. mertensii* (Grev.) Harv., *P. preissianum* Sond., *Phacelocarpus labillardieri*, *Mychodea compressa* Harv., *M. carnosa* H. and H., *Gloiosaccion brownii* Harv., *Hymenocladia polymorpha*, *Antithamnion mucronatum* (J. Ag.) De Toni, *Ballia scoparia*, *B. callitricha* J. Ag., *Ceramium puberulum* Sond., *Dasyphila preissii* Sond., *Euptilota articulata* (J. Ag.) Schmitz, *Lasiothalia formosa* (Harv.) De Toni, *Monospora elongata*, *Muellerena insignis*, *Spongoclonium* sp., *Spyridia opposita*, *Sarcomenia dasyoides*, *Polysiphonia mallardiae* Harv., *Brongniartella australis* (Ag.) Schmitz., *Doxodasya bulbochaete* (Harv.) Falk., *Amansia pinnatifida* Harv., *Aneuria latifolia* (Harv.) J. Ag., *Osmundaria prolifera* Lamx., *Dasya naccarioides* Harv., *Thuretia quercifolia* Dcne.

OCCASIONAL: *Gulsonia annulata* Harv. (rare), *Delisea pulchra* Mont., *Brachycladia marginata* (Sol.) Schmitz, *Callophyllis coccinea* Harv., *Gelinaria ulvoidea* Sond., *Thamnoclonium claviferum* J. Ag., *Peyssonnelia australis* Sond., *Metagoniolithon stelligerum* (Lamx.) W. v. B., *Corallina pilifera* Lamx., *Areschougia gracilarioides* (?), *Thysanocladia laxa* Sond., *Erythroclonium angustatum* Sond., *Gloiophyllis barkeriae* (Harv.) J. Ag., *Rhodophyllis tenuifolia* (Harv.) J. Ag., *Plocamium angustum*, *P. leptophyllum* Kütz., *Phacelocarpus sessilis* Harv., *Stenocladia harveyana* J. Ag., *Acrotylus australis* J. Ag., *Gigartina disticha* Sond., *Iridaea australasica* J. Ag., *Champia affinis* (H. and H.) J. Ag.,

C. tasmanica Harv., *Gloioderma tasmanica* Zan., *Rhodymenia australis* (Sond.) Harv., *Hymenocladia usnea* J. Ag., *Antithamnion dispar* (*Harv.*) J. Ag., *Griffithsia antarctica*, *Ceramium isogonum* Harv., *Crouania vestita* Harv., *Ptilocladia pulchra* Sond., *Spongoclonium brownianum* (Harv.) J. Ag., *Wrangelia crassa* H. and H., *W. myriophylloides* Harv., *W. princeps* Harv., *Sarcomenia delesserioides* Sond., *Hypoglossum microdontum* J. Ag. (?), *Claudia elegans* Lamx., *Polysiphonia davyae* Reinb., *Cladurus elatus* (Sond.) Falk., *Coeloclonium opuntioides* (Harv.) J. Ag., *Laurencia filiformis* Mont., *Jeannerettia lobata*, *Protokützingia australasica* (Mont.) Falk., *Amansia kützingioides* Harv., *Lenormandia marginata* H. and H., *L. muelleri* Sond., *L. smithiae* (H. and H.) Falk., *Trigenia umbellata* J. Ag., *Halodictyon robustum* Harv., *Dasya villosa* Harv., *D. haffiae* Harv., *Heterosiphonia muelleri* (Sond.) De Toni.

SEASONAL VARIATION IN THE ALGAL FLORA

(a) *Seasonal occurrence*

The great majority of the algae growing on the Pennington Bay rock platforms are present throughout the year. The larger brown algae, nearly all members of the Fucales, are the most stable species, and probably live for several years.

The *Ectocarpus confervoides* and *Pylaiella fulvescens* seasonal associations are the only ones limited in their occurrence to definite periods of the year. Certain characteristic species within other associations, particularly the *Cystophora*—coralline and sublittoral fringe associations, are also seasonal. In both these asociations *Monopora elongata* and *Griffithsia monilis* are found only during winter months, although the former is occasionally cast up from the sublittoral in summer. *Nemastoma feredayae* is strictly a summer species. A number of epiphytes are also of seasonal occurrence. *Corynophloea cystophorae* is epiphytic on the receptacles of *Cystophora intermedia* and *C. siliquosa* during the summer, while a species of *Dasya* and *Crouania muelleri* epiphytise the same species of *Cystophora* mainly during winter months.

Species dealt with under "Chance distribution of minor species" are very irregular in their occurrence and apparently not restricted to any one period.

Information on seasonal occurrence of sublittoral species, derived from cast up plants, is not reliable, but definite collection records will be given in the census in a later paper.

(b) *Seasonal development of stable species*

Many species on the reefs attain their maximum development in the late winter. This is probably associated with lower sea temperatures. The seasonal development of vesicles in *Cystophora uvifera* and of the fertile fronds of *Sargassum muriculatum* has been described on pages 154 and 155. Other species of *Sargassum* cast up from the sublittoral are best developed in late winter when the fertile fronds are borne. In this state the plants are most easily torn off and cast up.

The *Cystophora*—coralline association is better developed in winter when the corallines are actively growing. *Rivularia firma* and *Enteromorpha acanthophora* attain their maximum size in late winter.

(c) *Seasonal variation in reproduction*

Many species have been found bearing reproductive organs on every visit to Pennington Bay (at approximately 2-monthly intervals during 1947), and it is probable that most species are not strictly limited to any one period of the year.

Whether any monthly cycle in reproduction correlated with the tidal cycle occurs is not known, but is unlikely, as monthly tidal variation on the south coast of Kangaroo Island is small and its effect minimised by constant breakers.

During late winter (September) nearly every species on the reef bears reproductive organs, usually abundantly, and this time seems to be the most favourable period for reproduction. In September 1946 it was difficult to find a specimen of most of the small Rhodophyceae—such as *Champia obsoleta*, *Muelleren*a sp., *Monospora elongata* and *Liagora harveyana*—not bearing reproductive cells, but at other times (*e.g.*, mid-summer) most specimens are sterile. Often 80% or 90% of the plants of diplobiontic Rhodophyceae are tetrasporic, while very few plants are spermatangial.

Liberation of zoospores and gametes in *Enteromorpha* and *Ulva* is probably dependant on sufficiently long exposure during very low tides. Most of the fucoids are fertile throughout the year, but the species of *Sargassum* produce fertile fronds in winter and lose them in early summer.

VARIATION UNDER WAVE ACTION

Stunting of algae under severe wave action is a general feature of species which grow both in the sublittoral proper and the sublittoral fringe or *Cystophora*—coralline associations. The roughest situations always show the densest algal growth, but reduction in the degree of branching in some (*e.g.*, *Hymenocladia polymorpha, Dasyopsis clavigera*), and increase in branching from the base giving compact tufted forms in others (*e.g.*, *Cladophora valonioides*) are the most general adaptions to withstand the mechanical force of the breakers. *Cystophora intermedia*, which grows best in the roughest localities and not on calmer coasts, is one notable exception to stunting under rough conditions.

In many cases it is evident that size and gross external form are of little use as specific characters. Normally pinnate or well-branched forms may become simple or nearly so on the edges of reefs, and all variations of form between the extremes occur in intermediate habitats. Other species may retain distinctive branching in all habitats, but until the range in form of a species under varying environmental conditions is known, differences in size and degree of branching can be used in separating entities only with great caution. Internal tissues and cell structure, on the other hand, are usually reliable. All stunted species on the reef edges become fertile and must therefore be considered as mature plants.

The variation in *Dasyopsis clavigera* has been described previously (Womersley 1946). The following examples also illustrate the type of variation found.

Hymenocladia polymorpha on the reef edge consists of a few (2 to 5) unbranched elongate fronds from a common base, up to 12 cm. high, but sublittoral forms are pinnately and often bipinnately branched and reach a height of 70 cm.

Cladophora valonioides—Sublittoral forms are loosely branched, often with one or a few main filaments, and to 20 cm. or more tall. In calmer parts of the reefs it is 5 to 10 cm. tall, but on the edge of the reef the thallus is a hemispherical mass of filaments only 2 or 3 cm. high.

Laurencia heteroclada—The variation in form of this alga was commented on by Harvey (1860, pl. cxlviii), and similar variation occurs in the Pennington Bay forms. Small, poorly branched specimens are always found in rough places or in shallow water.

Caulerpa spp.—The species of *Caulerpa* found growing in outer deep rock pools on the reef (p. 160) are stunted when compared with cast-up specimens, but the degree of branching and external form is fairly constant. When growing on the reef surface stunting is even more pronounced, while shade from other algae or pool edges allows development of larger fronds.

PARASITISM AND EPIPHYTISM

When describing the various associations, the common epiphytes on other algae have been listed. In nearly every case it appears that the epiphytic alga uses the "host" only as a suitable form of attachment, there being no intimate physiological relation between the two. This is indicated by the wide range of "hosts" of many epiphytes, and also by the ability of most to grow on bare rock as well. As yet no critical examination of the method of union of epiphyte to host has been made.

One exception is that of *Notheia anomala* on *Hormosira banksii* (see Williams 1923), in which there appears to be some definite relationship as *Hormosira* is the only alga at Pennington Bay on which *Notheia* will grow. Although this case is usually referred to as "parasitism," it is only partial, for it is very doubtful how much, if any, nutrient *Notheia* derives from its host.

Several other species appear to favour certain hosts because of the rough nature of the stems or presence of conceptacles which provide suitable germination places. *Cystophora paniculata* has unusually rough stems and usually shows profuse epiphytic growth. On a single plant of this species the following species will often be found: *Polysiphonia nigrita, Mychodia foliosa, Thuretia teres, Antithamnion hanowioides, Melobesia* sp. and fragments of *Corallina*. Most other species of *Cystophora* have smoother stems, and epiphytes grow mainly from the conceptacles. Species of *Dasya* and *Crouania muelleri* are frequently found on *C. intermedia* and *C. siliquosa*. *Jania fastigiata* grows on the stems of *C. subfurcinata* very heavily in the *Cystophora*–coralline association, while *Polysiphonia nigrita* is very prevalent on *Scytothalia dorycarpa* in outer rough pools.

Epiphytes on algae growing in calmer parts of the reef are much sparser. *Sphacelaria biradiata* and *Sph. furcigera* are commonly found on *Cystophora uvifera* and *Cystophyllum muricatum*, but any others are usually microscopic.

Detailed information on recorded hosts for all species will be given in the census.

VERTICAL DISTRIBUTION IN RELATION TO LIGHT

The horizontal surface of the Pennington Bay reefs provides a large area for algal growth subject to fairly uniform light conditions. Only below the reef edge, or in deeper pools, where algae are constantly submerged and the water in a turbulent state does light intensity fall off greatly. These reefs are therefore suitable for estimating the numbers and percentages of the algae which are restricted to the reef surface (*i.e.*, with high light intensity) and those restricted to the sublittoral (lower light intensity). This data for the Pennington Bay region is presented in Table II.

TABLE II

Distribution of the Algal Classes in the Littoral and Sublittoral

	Myxophyceae	Chlorophyceae	Phaeophyceae	Rhodophyceae	Total
Restricted to reef surface (littoral)	6	5	21	30	62
Restricted to sublittoral - -	0	14	38	90	142
Common to littoral and sublittoral	1	7	11	23	42
Total for each class - - -	7	26	70	143	246
Each class as % total - - -	3	11	28	58	100
% of each class in littoral - -	100	46	46	37	42

Numbers of species in the various divisions of the table are not necessarily exact, as some 30 unnamed species have not been included, and a few others have been omitted as insufficient specimens and information about them are available. The edge of the reefs has been used as a dividing line between littoral and sub-

littoral, but algae growing on the reef surface or edge in the sublittoral fringe are included in the littoral as the light relations are closest to true littoral conditions. It is inevitable that there is a personal factor in drawing up such a table, but with the large numbers available this is probably small.

It is not suggested that light intensity is the only controlling factor in whether an alga grows on the reef or in deeper water. On the reef edge, degree of roughness is of considerable importance, but light intensity is the major factor for most species, and the edge of the reef is a natural line of division in this respect.

The total number of species collected from about one mile of fairly uniform coastline is over 270 (including unnamed species). On the main reef, an area of about 75 yards by 70 yards, some 60 or more species have been found. The Pennington Bay area is clearly a rich one, and numerous other species are probably still to be found.

The Rhodophyceae comprise over half the total number of species, and twice as many as the Phaeophyceae. Numbers for the Myxophyceae would be increased if microscopic species were thoroughly collected. On the reef surface there are more Rhodophyceae than any of the other groups, and more Phaeophyceae than Chlorophyceae. Most of the Rhodophyceae, however, occur on the outer rougher parts of the reefs.

When the percentage of each class in the littoral zone is estimated, the Chlorophyceae and Phaeophyceae give the highest figure, 46% for both. The proportion of Rhodophyceae in the littoral is lower, 37%, owing to the much larger numbers of red algae which are restricted to the sublittoral. All the species of Myxophyceae known from the region occur in the littoral.

The numbers of each class common to both littoral and sublittoral is relatively small, and most of these occur near the edge of the reef in rough conditions, where the light intensity at high tide is slightly lower than on the reef surface proper.

The Chlorophyceae and Phaeophyceae show no difference in the proportions of each class in higher or lower light intensities, but owing to the larger numbers of the browns, more species than the greens are found on the reefs and also in the sublittoral. The proportion of Rhodophyceae in the littoral is small, showing that red algae do tend to grow in deeper water, but owing to their much greater numbers, more occur in the littoral than the other classes.

The long standing concept of a broad vertical distribution of green, brown and red algae, in that order, holds only for the Rhodophyceae at Pennington Bay. Red algae cast up from deep water are always a brighter red in colour than reef forms, which are often yellowish-brown. Myxophyceae, however, show a strong tendency to grow in bright light intensities, though the thick gelatinous sheaths of most species must greatly reduce the amount of light reaching the actual cell.

SUMMARY

The algal associations of the wave-cut rock platforms of the Pennington Bay region are described. These are classed into supralittoral (*Prasiola* community only), littoral, and sublittoral fringe associations, while the deeper sublittoral flora is also listed.

Most of the flat surface of the reefs is covered by the *Cystophora* complex (including several associations) and the *Hormosira banksii* association, while the rich and dense *Cystophora intermedia* association is characteristic of the sublittoral fringe on the edge of the reefs. Other important associations are those of *Rivularia firma*, *Ectocarpus*--*Pylaiella* (seasonal), *Enteromorpha*, *Cystophyllum* and *Cystophora*--coralline.

Although the reef surface is remarkably horizontal, differences in height of only a few inches cause clear-cut changes in the algal associations. The densest associations are those in the roughest places, where stunting of most species is pronounced. Associations in calmer regions are sparse in number of species, with considerable bare rock between plants, but often consist of larger individual plants.

The algal flora of the region is very rich, over 270 species having been found along 1½ miles of coast. Seasonal variation in the algal flora is discussed, and examples given of the great variation in external form of many species caused by different degrees of wave action. Data on the vertical distribution of the algal classes in relation to light intensity is also given.

Correction to Part I (Womersley 1947)

For *Acrotylus australis* read *Xiphophora chondrophylla* (R. Br.) Harv. [pp. 241, 242, 247; and legend to fig. 3 (p. 239)]. The provisional determination of this alga was based on sterile material, and fertile specimens collected in January 1948 show that it is the brown alga *Xiphophora chondrophylla*. In external form and T.S. of the thallus the resemblance to *Acrotylus* is remarkable. Our specimens are probably a small form of the var. *minus* J. Ag. The species has not been previously recorded from South Australia.

ACKNOWLEDGMENTS

In addition to the acknowledgments made in the first paper of this series, the author is grateful to Dr. Tore Levring, of Sweden, for the use of photographs of the algae at Pennington Bay, taken on a visit with the author during January 1948.

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EXPLANATION OF PLATES X TO XV

PLATE X

Fig. 1 View of Pennington Bay from the east, with a low, calm sea. The main reef is in the left centre, and other reefs can be seen at the base of small rocky outcrops further around the bay.

Photo T. Levring

PLATE XI

Fig. 1 The main reef, Pennington Bay, from the cliffs above. The dark areas on the outer parts are covered with *Hormosira*, while the sandy pool is on the lower right. Photo taken at a very low tide.

Photo H. B. S. W.

Fig. 2 The western terraced reef, Pennington Bay, during a very low tide. The second level bears the *Hormosira*-anemone rock pools, with dense masses of the black bivalve *Modiolus* on and just below this level.

Photo H. B. S. W.

PLATE XII

Fig. 1 The eastern part of the fallen rock region. The mixed *Cystophora* association covers the foreground.

Photo H. B. S. W.

Fig. 2 The fallen rock region on the main reef, during a calm high tide. *Symploca hydnoides* occurs on the wave washed rock, with *Rivularia firma* just above and below water level in the photo.

Photo H. B. S. W.

Fig. 3 Rock, normally covered by the sandy beach, exposed in September, 1946. On the wave washed rock *Ectocarpus* and *Enteromorpha* associations were well developed.

Photo S. J. E.

Fig. 4 *Ectocarpus confervoides* densely covering rock shown in Figure 3.

Photo H. B. S. W.

PLATE XIII

Fig. 1 *Hormosira banksii* association on ridged rock. *Hormosira* only occurs on the ridges, where it is exposed at low tide, with bare or sand covered rock between each ridge.

Photo T. L.

Fig. 2 Junction between the *Hormosira* and mixed *Cystophora* association on the channel edge. The sudden change due to a drop of 3 or 4 inches in the height of the reef is clearly shown.

Photo T. L.

Fig. 3 *Hormosira banksii* association, showing slight intermixture with *Cystophora*.

Fig. 4 The *Hormosira*-anemone pool on the western terraced reef. The anemones appear as dark areas in hollows on the rock at the far side of the pool.

Photo H. B. S. W.

PLATE XIV

Fig. 1 The ledge on the main reef, looking shorewards. The beach was heavily sanded up at this time (January 1948). The mixed *Cystophora* association of the channel is shown on the left of the ledge.

Photo T. L.

Fig. 2 The ledge on the main reef, from the fallen rock region. The alga in the left foreground is *Cystophyllum*, with some *Cystophora uvifera*.

Photo T. L.

Fig. 3 The mixed *Cystophora* association, showing almost pure *C. uvifera*. *C. subfarcinata* occurs on the lower left.

Photo T. L.

Fig. 4 The eastern edge of the main reef, showing the sudden drop off into deep water. *Cystophora intermedia* forms a dense fringe hanging down the side.

Photo I. Thomas

PLATE XV

Fig. 1 The *Cystophora*-coralline association on the main reef. The black tufts are *Cystophora paniculata*, the lighter coloured fronds *C. subfarcinata*. *Corallina* and *Jania* appear as light coloured patches.

Photo T. L.

Fig. 2 Close up view of the *Cystophora*-coralline association. The white pinnate fronds of *Corallina* and dense tufts of *Jania* contrast with the dark fronds of *Cystophora subfarcinata*, with some *Hormosira* also present.

Photo H. B. S. W.

Fig. 3 The outer, highly dissected part of the main reef, where the sublittoral fringe association is developed. Photo taken at a very low tide.

Photo I. T.

Fig. 4 The *Cystophora intermedia* association of the sublittoral fringe. This alga is prominent on the left of the photo, with *Sargassum bracteolosum* in the centre and a plant of *Codium pomoides* above the latter.

Photo H. B. S. W.

Fig. 1

Fig. 2

Fig. 2

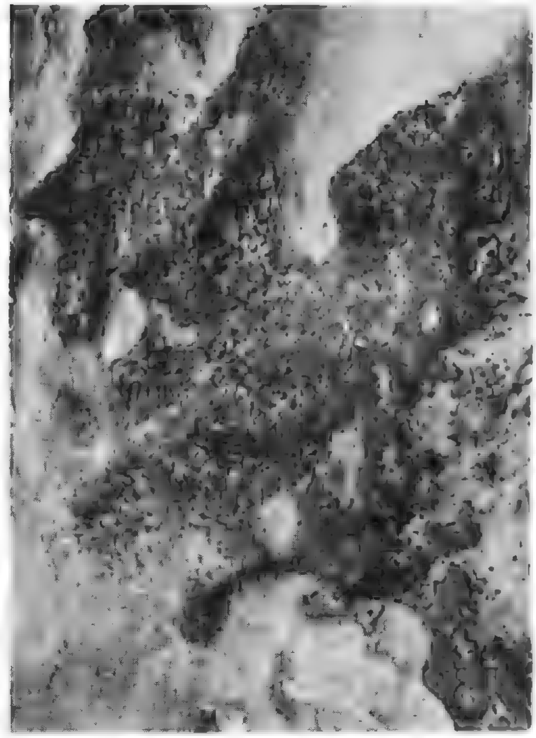

Fig. 4

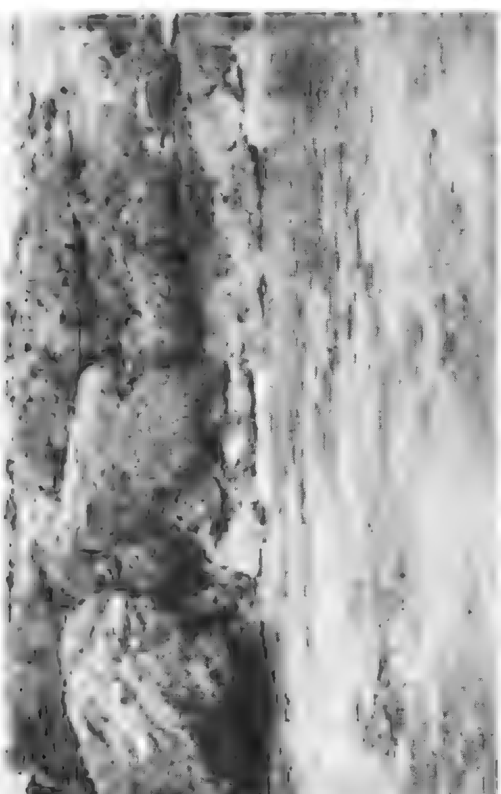

Fig. 1

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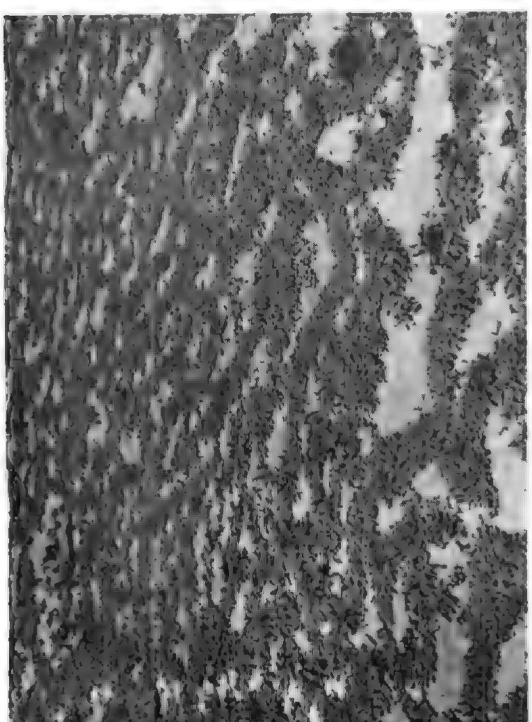

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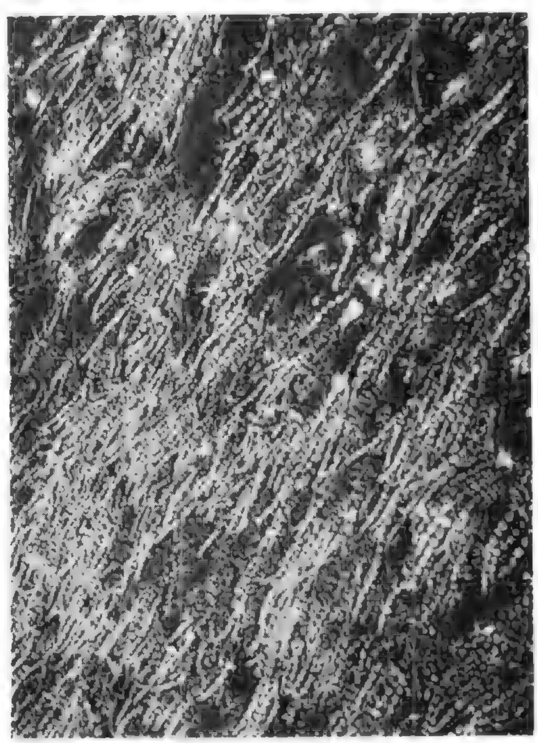

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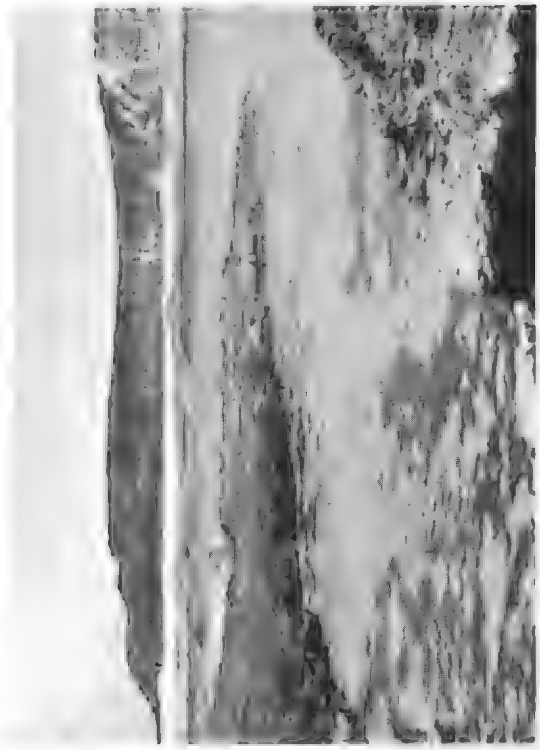

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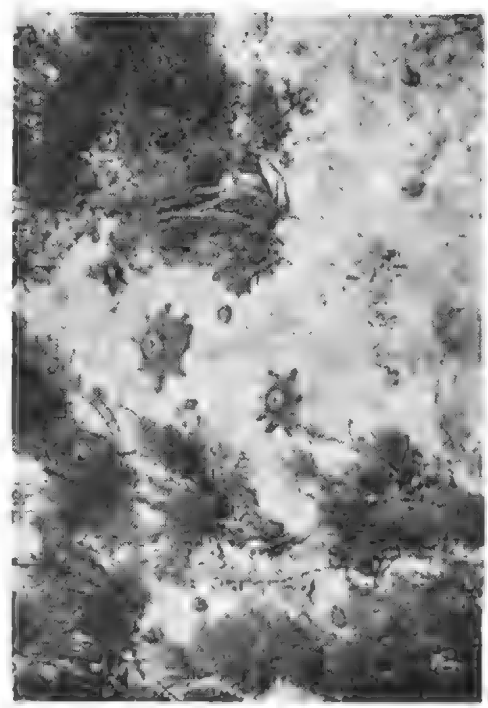
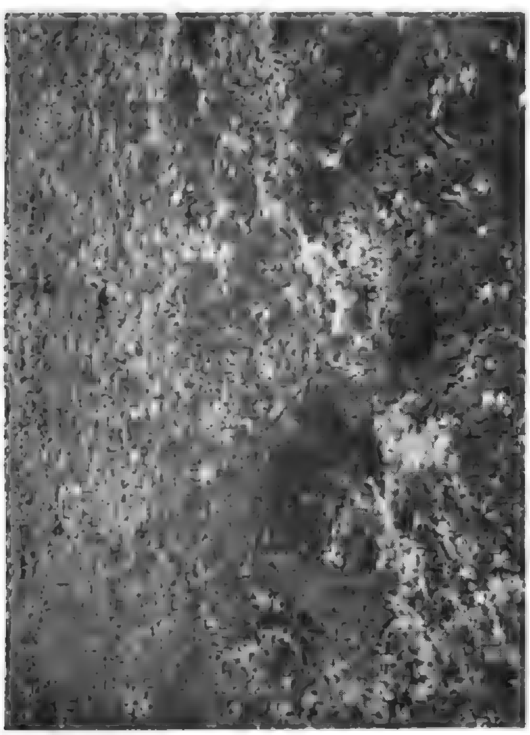


Fig. 3


Fig. 2


Fig. 4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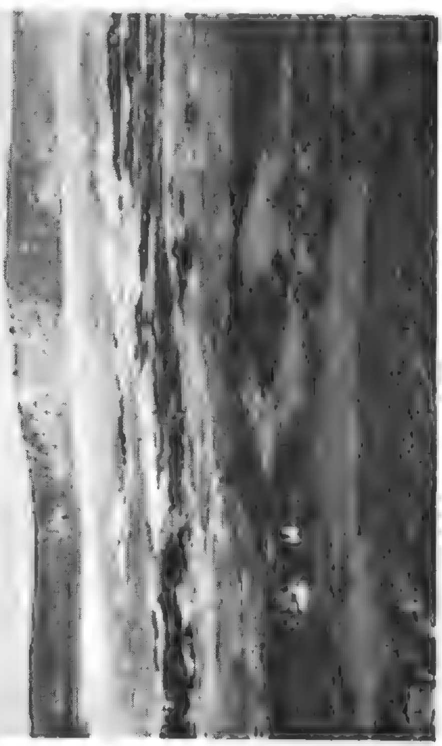
Fig. 3

THE COMMONER SPECIES OF ANIMALS AND THEIR DISTRIBUTION ON AN INTERTIDAL PLATFORM AT PENNINGTON BAY, KANGAROO ISLAND, SOUTH AUSTRALIA

BY S. J. EDMONDS

Summary

This paper deals with the commoner species of animals and their distribution on a rock platform at Pennington Bay on the south coast of Kangaroo Island, South Australia. An examination of the fauna of this reef has been made by the writer during a number of University vacations from 1944-47. At the same time Mr. H. B. S. Womersley of the Botany Department, University of Adelaide, has been working on the algal ecology of the island and this reef (Womersley 1947, 1948).

THE COMMONER SPECIES OF ANIMALS AND THEIR DISTRIBUTION ON AN INTERTIDAL PLATFORM AT PENNINGTON BAY, KANGAROO ISLAND, SOUTH AUSTRALIA

By S. J. Edmonds*

[Read 8 July 1948]

Contents

1. INTRODUCTION AND ACKNOWLEDGMENTS

This paper deals with the commoner species of animals and their distribution on a rock platform at Pennington Bay on the south coast of Kangaroo Island, South Australia. An examination of the fauna of this reef has been made by the writer during a number of University vacations from 1944-47. At the same time Mr. H. B. S. Womersley of the Botany Department, University of Adelaide, has been working on the algal ecology of the island and this reef (Womersley 1947, 1948).

The author wishes to acknowledge the help which he has received from many people. His thanks are due to Prof. T. H. Johnston and Mrs. P. M. Thomas of the Adelaide University, and Miss E. C. Pope of the Australian Museum, Sydney, for advice and encouragement, and to Mr. H. B. S. Womersley for discussions and suggestions; and to the following who identified many of the specimens collected: Mr. H. M. Hale (Museum, Adelaide)—Crustacea; Mr. B. C. Cotton (Museum, Adelaide)—Molluscs; Dr. E. A. Briggs (University, Sydney)—Hydroids; and Mr. K. Sheard (C.S.I.R.)—Amphipods. He also wishes to thank those senior students and research assistants of the Zoology Department of the Adelaide University, in particular Mr. R. Specht and Miss H. G. Clark, who have helped with the collecting and counting.

2. A GENERAL DESCRIPTION OF THE ROCK PLATFORM AND ITS ENVIRONMENT

Although a complete description of the reef has been given by Womersley (1948) it seems necessary that a brief description, at least, should also be made here in order to give this paper some unity. The platform, which is almost horizontal, lies between the levels of high and low water neap tides and is composed of calcareous sand rock of recent origin. It is washed by the waters of the Southern Ocean and at high tide wave action over most areas of the reef is strong. The substratum is generally rocky. Near the shore, towards the west, sand is usually deposited on the rock. A few large boulders, which can be moved only with great difficulty, rest on the platform at the eastern end of the reef.

* Zoology Department, University of Adelaide.

They have formed where the cliffs have collapsed. No loose stones are to be found, and therefore those communities which usually inhabit the undersurfaces of loose rocks are not present. Most of the animals which live on the reef cling firmly either to the rock or the dense growth of algae which is present. Womersley (1948) has drawn attention to the richness and dominance of the algae on this reef. There are two small rock pools filled by wave splash high up in the supra-littoral region. Further description of the reef is given, where necessary, in other parts of this paper.

About a mile west of the main reef at Pennington there is a much smaller rocky formation where the calcareous sand rock has been cut into three or four wave-cut terraces. A study of the distribution of the animals on this reef has thrown light on the zonation of the animals on the main reef. When this reef is mentioned it is referred to as the "western terraced reef".

An account of the environmental conditions of the coasts of Kangaroo Island and at Pennington Bay is given by Womersley (1947) and (1948). The hydrological determinations were made jointly by us. At Pennington Bay the tidal range is about $2\frac{1}{2}$ feet at spring tides and $1\frac{1}{2}$ feet at neap tides. The temperature of sea measured off the edge of the platform at irregular intervals during the year ranges from 19·0° C. in summer to 13·5° C. in winter. The temperature of the water on the reef is usually within 1° C. of the sea temperature. The salinity of the water determined during summer months varies between $35{\cdot}2^0/_{00}$ and $35{\cdot}4^0/_{00}$, and its pH. by colorimetric methods is about 8·2-8·3.

3. EXPLANATION OF TERMS

The terms *"littoral"*, *"supra-littoral"* and *"sub-littoral fringe"* are used in this paper to describe the different horizontal regions on the rock platform. The meaning given to these terms by workers in marine ecology often differs slightly. The author in this paper has adopted the usage of Oliver (1923) and Cranwell and Moore (1938), and given a broad meaning to the term "littoral". The littoral or intertidal is considered to be that region lying between the highest wash of the waves and the level of the low spring tides. The supra-littoral is the spray region, and its lowest levels may be washed or splashed during exceptionally rough weather. The sub-littoral fringe is a very narrow region which is usually covered by the sea but which is sometimes exposed at the lowest tides in very calm weather or at low tide when the wind is off shore.

Elizabeth Pope (1943), in her study of the plant and animal communities at Long Reef, New South Wales, fixed the upper limit of the littoral region as that of the average high water spring tides. On account of the much smaller tidal range and the roughness of the sea at Pennington Bay the heights of the tides cannot be determined as precisely as at Long Reef.

Early in the study of the fauna of this and neighbouring reefs, it was seen that in many cases the distribution of animal life is closely connected with the distribution of plant life. This is particularly noticeable in the case of the weed-feeding molluscs. Consequently reference is made in this paper from time to time to the algae found on the reef.

4. REGIONS OF THE PLATFORM

A. Supra-littoral

The supra-littoral is rocky and the dominant inhabitant is the periwinkle, *Melaraphe unifasciata*. Algae are not well established, but patches of a lichen of the genus *Lichina* are occasionally observed. *M. unifasciata* climbs highest of all the molluscs on the reef and is found in great numbers on the tops and

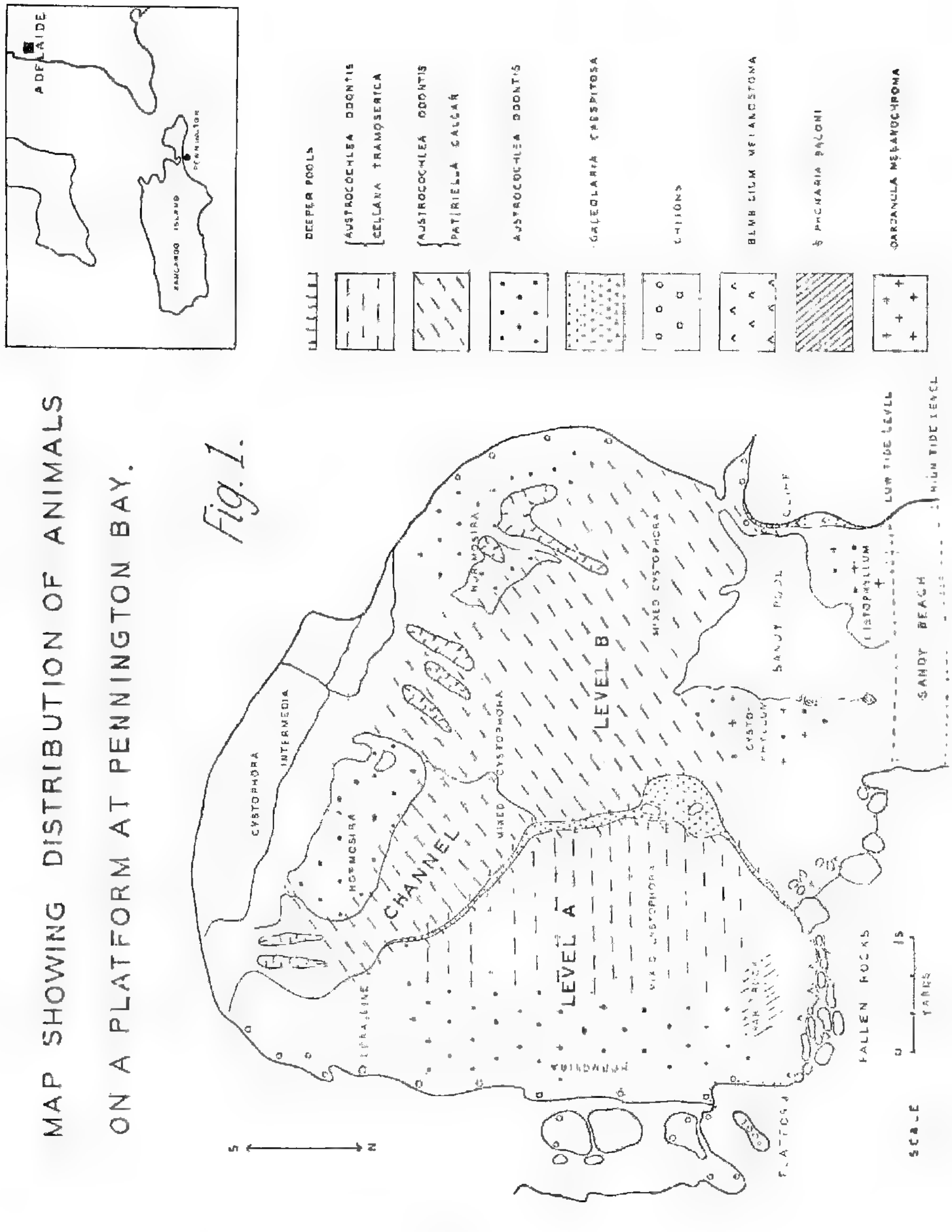

Fig. 1

sides of rocks. A fact perhaps worth recording is that the noddiwink, *Noddilittorina tuberculata,* found on the highest levels at Long Reef, New South Wales, does not occur here.

In the more sheltered parts of the supra-littoral the quick moving isopod, *Ligia australiensis*, is common and hurries out of sight as one walks over the rocks. Occasionally the large yellow crab, *Leptograpsus variegatus*, is found in the lower levels sheltering in crevices or under ledges of rock.

At the eastern end of the reef there are two small shallow and isolated rock pools filled with water from splash and spray. In summer months the temperature of the water in these pools has been as high as 35° C., and the salinity $40 \cdot 2^0/_{00}$. The following species have been collected from them: *Melaraphe unifasciata*, which forms thick clusters at the edge of the water; and occasionally *Bembicium melanostoma, Siphonaria baconi, Siphonaria diemenensis* and *Galeolaria caespitosa.*

B. Littoral

The greatest area of the reef lies in this region. The upper limit of the littoral varies from 1 to 5 feet above the level of high water spring tides, and the lower limit is that of the low water spring tides. The littoral consists of (a) the more or less vertical cliff face at the rear of the reef, some immovable boulders at the eastern end and an area of sand towards the western end of the platform, and (b) the platform itself which lies between the levels of high and low water neap tides. An idea of the size and shape of the platform can be obtained from fig. 1. Although the platform appears to be horizontal, the drainage of the water from its surface shows that it dips slightly towards the west. A most noticeable structure on the platform is a narrow ledge of rock 2 to 5 inches high which arises at the south-east corner, runs to the centre of the reef and then curves to the north-east corner. The highest levels of the platform are the areas between this ledge and the shore (level A in fig. 1) and the outermost parts of the platform, marked by a very dense growth of *Hormosira*. A narrow channel, 6 to 12 inches lower than level A, arises between the ledge and the *Hormosira* at the south-east corner of the platform. This channel runs south-west, gradually widens out and eventually becomes the main level of the platform near a sandy pool at the north-west corner (level B in fig. 1). This sandy pool always contains water. The surface of the platform is rocky and uneven and contains depressions and holes from 1′ to 2′ 6″ deep. A thin layer of loose sand up to 1″ thick may be deposited on the rocky surface of both levels A and B near the shore. Although the platform is above the level of the low tides its surface is rarely dry. There are two reasons for this. Firstly, the platform is so eroded and uneven that a considerable quantity of water is always retained on its surface when the tide recedes. Secondly, wave action even at low tide is strong and waves which break against the seaward face of the platform wash over its surface. There always appears to be a wash of water down the channel to the north-west corner. At low tide the dense growth of algae tends to lie flat on the reef, thus reducing the exposure of its surface. The eastern and western faces of the reef are either vertical or undercut by wave action. The seaward face of the reef is very uneven, broken and dissected.

a. Animals on the Cliff Face at the rear Littoral

The fauna of this subdivision of the littoral consists chiefly of barnacles, molluscs and serpulid worms.

Barnacles

(i) The highest level of the littoral is marked by a well-developed zone of barnacles of which *Chthamalus antennatus* is the most numerous. *C. antennatus* occurs on the tops and sides of rocks below high water spring tide level and on rocks above the high water line which are splashed or washed. Algae rarely occur at this level. Small groups of the honeycomb barnacle, *Chamaesipho columna* are found here and there amongst the *Chthamalus* at the lower levels. Well developed communities of *Chamaesipho columna* have been noticed on sloping rock surfaces at other localities along this coast. Adult and juvenile specimens of *Melaraphe unifasciata* occur amongst the barnacles of this zone. Tubes of the polychaete, *Galeolaria caespitosa,* are scattered where the rocks are well splashed or washed. *C. antennatus* and *G. caespitosa* often cluster together in the small gutters or channels down which water drains back to the sea.

(ii) The barnacle, *Tetraclita purpurascens* forms a covering on the tops and sides of rocks and on the undersurfaces of overhanging cliffs which are subject to wash and wave action and which are protected from the sun. The alga, *Symploca hydnoides*, occurs in the same situation.

(iii) In the rougher and more exposed parts of the littoral at the eastern and western extremities of the reef where the cliff face is protected from the sea only by a narrow platform or by fallen rocks the surf barnacle, *Catophragmus polymerus*, can be collected. A few isolated specimens of *Balanus nigrescens* also occur here. These two barnacles are not common on this platform, but at many other localities along the coast they form well-developed communities. *Balanus nigrescens* at these places is found in the roughest parts of littoral where the sea surges up over rocks. There is a particularly good development of *Catophragmus polymerus* below the *Chthamalus* on the cliff face of the western terraced reef at Pennington Bay.

Molluscs

The lower level of the barnacle zone gradually merges with a zone of molluscs consisting of (a) a band of gastropods of the *Notoacmea – Siphonaria* type and (b) a narrow and sharply defined band of the blue-black bivalve, *Modiolus pulex*. Specimens of *Melaraphe unifasciata*, *Chthamalus antennatus* and *Galeolaria caespitosa* are scattered throughout this mollusc zone. *M. unifasciata*, however, rarely extends as low as the *Modiolus*, but it is common to find specimens of *C. antennatus* growing on the bivalve.

(i) The *Notoacmea – Siphonaria* band of molluscs contains the following species: *Notoacmea scabrilirata, Notoacmea septiformis, Actinoleuca calamus, Chiazacmea conoidea, Siphonaria diemenensis,* and sometimes *Bembicium melanostoma* and *Siphonaria baconi*. The vertical width of the band varies from 1½′ to 5′. The author has not been able to determine satisfactorily the zonation of these gastropods at Pennington Bay. *S. diemenensis, S. baconi* and *B. melanostoma* are usually found at the lower levels. *B. melanostoma* occurs only on the more protected rock surfaces where wave action is not strong.

(ii) The band of *Modiolus pulex* is not as well developed here as it is on the western terraced reef, where it covers a horizontal level about 2′ to 3′ wide just above the *Hormosira – Actinia* pools. Specimens of the smaller bivalve, *Kellia australis*, are always associated with *M. pulex*. The latter has not been observed in the more exposed parts of the coast.

Serpulid Worms

There is a well-developed zone, in which *Galeolaria caespitosa* is most noticeable, on the lower levels of the cliff face where the surface is rounding off to

form the platform. The tubes, however, are not as thick as the dense deposits observed in more sheltered localities on the island, *e.g.*, at Rocky Point near American River, and at Middle River on the north coast. *G. caespitosa* is scattered over a wide area at Pennington in the mid to higher littoral region wherever there is a good movement of water and no sand. It is commonly associated on this reef with the alga *Rivularia firma*. Scattered tubes of *G. caespitosa* and dark blobs of *R. firma* are particularly well developed on the ledge of rock which runs along the shoreward edge of the channel area of the platform. This ledge is about 2″-5″ higher than level A and water moves quickly over its surface. Tubes of *G. caespitosa* in much reduced numbers can be found almost anywhere on the platform itself.

OTHER ANIMALS

(i) Where the cliff face is nearer the open sea, and especially where there is a surging of water, a few specimens of the chitons, *Poneroplax costata* and *P. albida*, can be collected. The larger crabs are not common on this reef, probably because it offers them little shelter and protection. The following species have been collected: *Leptograpsus variegatus*, *Cyclograpsus audouinii*, *Ozius truncatus* and *Plagusia chabrus*. At the water level and on moist rock surfaces the amphipod, *Hyale rupicola*, is common.

(ii) The region of the boulders covers only a small portion of the reef towards the eastern extremity of the shore. The boulders, which are large and difficult to move, rest on the rock platform and have been deposited where the overhanging cliffs have collapsed. *Bembicium melanostoma*, *Galeolaria caespitosa* and the alga, *Rivularia firma*, are well established on and near the boulders. A few specimens of the littorinid, *Melanerita melanotragus*, are usually collected here. Both *B. melanostoma* and *M. melanotragus* are far more numerous on the upper levels of the intertidal region of the north and east coasts of the island or in the high rock pools at Vivonne Bay on the south coast. In these places there are more boulders and conditions are calmer. A smaller variety of *B. melanostoma* is very common on the higher levels of the intertidal flats at American River. The boulders afford shelter for the crabs listed above and for a few specimens of the red viviparous anemone, *Actinia tenebrosa*. This anemone is particularly numerous in and around the edges of the *Hormosira* pools of the western terraced reef.

(iii) The sandy portion of the rear part of the littoral consists of loose sand which is inimical to animal life. The small isopod, *Actaecia pallida*, is sometimes collected from the drier sand and the springtail, *Pseudanurida billitonensis*, from the moist sand.

b. ANIMALS ON THE ROCK PLATFORM

Plate XVI, fig. 2 and 3, and plate XVII, fig. 1, give some idea of the richness and density of the algal growth on the rock platform. Womersley (1948) considers the most important of these algal associations to be: (1) a *Cystophyllum muricatum* association which is developed between the sandy pool and the ledge of the main reef; (2) a *Cystophora* complex which covers the greater part of the reef and which contains several species of the genus *Cystophora*, *viz.*, *C. uvifera*, *C. subfarcinata*, *C. siliquosa*, together with *Sargassum muriculatum*; (3) a *Hormosira banksii* association which is most prominent on the higher parts at the outermost edge of the platform; and (4) a *Cystophora*—Coralline association on the rougher and more exposed south-east corner.

Weed-feeding molluscs are found in all these algal associations except the *Cystophora*—Coralline association. *Dardanula melanochroma* is found on the *Cystophyllum* and *Austrocochlea odontis*, and to a less extent *Phasianotrochus*

bellulus and *Zemitrella yorkensis* on the *Cystophora* and *Hormosira*. Particular reference might be made to the widely distributed alga, *C. uvifera*, which is squat and bushy. It is usual to find the following in or on this alga: *Austrocochlea odontis*, *Cominella* spp., *Subninella undulatus*, *Phasianotrochus bellulus*, *Zemitrella yorkensis*, *Gibbula preissiana*, a small white ophiuroid, *Amphipholis squamata*, *Nereis* sp., and numerous amphipods. The dominance of the algae on the outermost part of the reef is most apparent. The rocky substratum around the edge and down the vertical sides of the reef is covered with a thick carpet of short algae. Few animals, except chitons, are found here.

The chief fauna on the higher levels of the platform (level A, in fig. 1) consists of the weed-feeding molluscs, *Austrocochlea odontis* and *Cellana tramoserica*, in the channel region and level B *A. odontis* and the starfish, *Patiriella calcar*, and on the exposed edges of the reef the chitons, *Poneroplax albida* and *P. costata*.

Gastropods.

(i) *Austrocochlea odontis*

A. odontis is the most numerous and widely distributed mollusc on the platform and is found in most areas, even in some of the deeper pools and potholes along the outer edge of the reef. It is a strong and active creature and is found on both weed and rock. It seems to have a particular liking for *Cystophora uvifera* and *Hormosira banksii* and is associated with them on many reefs along the coast. With *Cellana tramoserica* it forms the principal animal community on level A, and with the starfish, *Patiriella calcar*, the principal community in the channel and on level B of the platform.

(ii) *Cellana tramoserica*

C. tramoserica lives only on the rocky substratum and apparently feeds on the microscopic algae which grow on its surface. *Austrocochlea odontis* and *C. tramoserica* are the principal fauna on level A. Very few specimens of this mollusc are found in the channel area, and it is never found where sand is deposited. It shows a tendency to gather in the larger depressions on the rocky surface of level A, where it will be exposed only occasionally. At other localities it has been noticed at much higher levels in the littoral, where it must withstand considerable exposure. Such places are the high rock pools at Vivonne Bay and the higher rocks at Cape de Coudie.

(iii) *Other gastropods*

Specimens of *Siphonaria baconi*, many possessing slightly eroded shells, are scattered over most areas of the platform. The species, however, is very prominent on the higher parts of level A, near the fallen rock area where the rocky substratum bears little algae. *S. baconi* often is found under thin layers of sand. *Patelloida alticostata* is common on the platform, more particularly at the higher levels, *e.g.*, on the ledge which runs across the platform. *Austrocochlea torri* occurs on the higher levels of the platform. *Cominella eburnea* and *Cominella lineolata* are found on the weed, on the rock or in the sand in most parts of the littoral region. Juvenile specimens of *Neothais textiliosa* and *Subninella undulatus* feed on the reef. They are, however, more numerous near the edges of the platform. *Floraconus anemone*, *Phasianella ventricosa* and the keyhole limpet, *Sophismalepas nigrata*, are sometimes collected on and amongst the algae. *Tethys norfolkensis* appears during the summer months. The algae and the rich epiphytic plant life which grows on it afford shelter, and probably food, for a number of gastropods other than *A. odontis*. Some of these molluscs are *Phasianotrochus bellulus*, *Phasianotrochus eximius*, *Gibbula preissiana*, *Cantharidus pulcherrimus*, *Zemitrella yorkensis* and *Zemitrella semiconvexa*.

Starfish

The chief fauna of the channel region and level B consists of *Austrocochlea odontis* and the eight-rayed starfish, *Patiriella calcar*. There is little doubt that the starfish are confined to this level because it is never completely exposed. When the tide is very low and the movement of water down the channel very slow and feeble, *P. calcar* seeks shelter in the deeper depressions or under algae. The thin and temporary layers of sand which are sometimes deposited near the sandy pool do not appear to be detrimental to this creature. It is common to find the starfish ingesting fragments of *Corallina cuvieri*. *P. calcar* has been noticed in crevices and pools on this and other reefs well below the level of the low water spring tides. Occasionally small flat isopods are found moving over the arms of the starfish.

Chitons

The outer edges of the reef are subject to strong wave action and are covered with algae. *Austrocochlea odontis* is rare here and is found only where there is shelter, *e.g.*, in cracks and under small ledges. The chitons, *Poneroplax albida* and *P. costata* are the only animals established on this part of the reef. They are found in shallow depressions on the edges and on the vertical sides of the platform and extend down to the sub-littoral fringe. Their plates are usually covered with tufts of small algae.

Other Animals

Crustacea are abundant in the algae. The small crabs, *Halicarcinus ovatus*, the weed crab, *Naxia tumida*, and the sea centipedes, *Paridotea munda* and *Euidotea peronii* are usually found in the weed. *Ozius truncatus* and *Eriocheir spinosus* are rare. A sphaeromid isopod is often collected in the algae but no burrows have been observed in the rock. The following amphipods have been identified, *Waldeckia chevreuxi*, *Elasmopus subcarinata*, *Amphithoe australiensis*, *Hyale nigra*, *Hyale rupicola*, and *Calliopus* sp.

The reddish-brown *Holothuria fuscocinerea* is often found in the algae or the sand which collects around the holdfasts of the more bushy species of weed. A small white and active ophiuroid, *Amphipholis squamata*, is usually collected at the base of *C. uvifera*.

The anemones, *Anthopleura muscosa* and *Bunodactis verotra*, occur on the platform. *A. muscosa*, with shell fragments attached to its exterior, is found in cracks, crevices and under ledges, while *B. veratra* is commoner amongst the algae.

Polychaets of the genus, *Nereis*, shelter in the holdfasts of the algae and tubes of *Spirorbis* sp. are common, especially on *Sargassum*. Scattered tubes of *Galeolaria caespitosa* occur on the rocky substratum where there is a good flow of water.

Two small fish are sometimes collected from amongst the weed; they are *Clinus perspicillatus* and *Syngnathus curtirostris*. Smaller specimens of *Myxus elongatus* and *Mugil cephalus* have been caught in and near the sandy pool. Tardigrades and numerous free-living nematodes, including *Epsilonema* sp. and *Trichoderma* sp., have been identified in material scraped off two rocks which project from the sand near the shore. Ascidians and sponges do not occur on the platform itself. Pycnogonida and nemertines are occasionally collected from among the algae.

C. Sub-littoral Fringe

The sub-littoral fringe comprises those parts of the reef near the level of the low spring tides which are exposed either momentarily between waves or when an offshore wind coincides with a low spring tide. It is the most inaccessible region of the platform and one rarely has an opportunity of examining its fauna.

The densest algal growth on the reef is found here and the rock is covered with plant life. Womersley (1948) points out that in an area of 4 or 5 square yards it is common to find 40 or 50 different species of algae and that epiphytic growth is profuse. The dominant algal association is one of *Cystophora intermedia*; other larger algae are *Sargassum bractiolosum* and *Ecklonia radiata*. The smaller algae are listed in Womersley's paper. The dominance of the plant life in the sub-littoral fringe and, as far as can be determined, the sub-littoral on this and other reefs of the south coast of this island is almost complete. The commonest animal in the sub-littoral fringe is the stalked ascidian, *Boltena australis* (*Pyura australis*), but its numbers, however, are not great. *B. australis* is found on those surfaces of the sub-littoral fringe which are almost vertical and it is usually concealed amongst the larger algae. Sometimes the chitons, *Poneroplax costata* and *P. albida*, extend down from the littoral into this region.

The *Balanus nigrescens*—*Pyura praeputialis* community of the sub-littoral fringe at Long Reef, New South Wales (Pope 1943), is not present at Pennington and has not yet been observed in South Australia by the writer. Nor is there here any animal growth which corresponds to the dense *Pyura stolonifera* community of the sub-littoral region at False Bay, South Africa (Stephenson 1937)

Larger specimens of *Subninella undulatus*, *Subninella torquatus*, *Neothais textiliosa* and *Haliotis roei* can be seen attached to rocks. Most of the other gastropods which live on the rock platform are not found in the sub-littoral fringe. Specimens of *Patiriella calcar* find their way into cracks and crevices. Colonial hydroids grow on many of the larger algae. The commonest species are *Sertularia minuta* and *Orthopyxis macrogona*, the latter usually being found on *Sargassum bractiolosum*. A sandy-coloured sponge is sometimes collected in the holdfasts of some of the algae. A red sponge and a red encrusting polyzoan are common on the ledges of rocks in this zone. When conditions are very calm a purple compound ascidian, *Austrobotryllus* sp., is sometimes collected from beneath the algae on the broken outer edges of the reef.

The fishes, *Scorpis georgianus*, *Pseudolabrus psittaculus*, *Pseudolabrus punctulatus* and *Myxus elongatus* have been caught off the eastern edge of the platform.

5. SUMMARY

The fauna of an intertidal platform of calcareous sand-rock has been examined. Wave action is strong and no loose stones are present. The most prominent animals on the cliff face at the rear of the reef are littorinid molluscs (*Melaraphe unifasciata*), barnacles (*Chthamalus antennatus*), molluscs and serpulid worms (*Galeolaria caespitosa*). On the platform itself the most prominent and the dominant life form is a thick growth of algae (*Cystophyllum muricatum*, *Cystophora* spp., *Sargassum muriculatum*, *Hormosira banksii*, Corallines and epiphytic algae). Weed-feeding molluscs (*Austrocochlea odontis* and *Cellana tramoserica*) are abundant on the algae and the platform respectively. Starfish (*Patiriella calcar*) appear on the lower levels and chitons (*Poneroplax albida* and *P. costata*) on the exposed edges of the reef. Algae (*Cystophora intermedia*, *Sargassum bractiolisum*, *Ecklonia radiata*, numerous smaller species and profuse epiphytic growth) are almost completely dominant in the sub-littoral fringe. Ascidians (*Boltema* (syn. *Pyura*) *australis*) are found, but not in great numbers, in the sub-littoral fringe. A list of the species collected is also given.

APPENDIX A

In order to determine the density of the mollusc and starfish population a metal frame 0·5 metre x 0·5 metre was constructed and thrown at random on the rocky substratum of the reef. The numbers of molluscs on both weed and

rock and starfish falling in the area enclosed by the frame were then counted. As a result of 100 throws on each of level A and level B the following averages were obtained:

	Level A	Level B
Cellana tramoserica - -	2·8	0·4
Austrocochlea odontis - -	10·5	12·0
Patelloida alticostata - -	0·5	0·2
Cominella spp. - - -	1·2	2·1
Zemitrella spp. - - -	0·5	0·7
Siphonaria baconi - -	5·0	0·4
Phasianotrochus bellulus -	0·2	0·4
Subninella undulatus -	0·1	0·9
Neothais textiliosa - -	—	0·2
Patiriella calcar - - -	0·1	4·0

APPENDIX B

List of animals collected at Pennington Bay

The species named are littoral except where otherwise indicated: sl. = supra-littoral; sbl. = sub-littoral; l. = littoral; + denotes that the animal is common.

COELENTERATA—*Actinia tenebrosa* Farqu., *Anthopleura muscosa* Drayton, *Bunodactis veratra* Drayton, + *Sertularia minuta* Bale sbl., + *Orthopyxis macrogona* (Lenden.) sbl.

PORIFERA—grey sponge growing on weed, red sponge. sbl.

NEMATODA—*Trichoderma* sp., *Epsilonema* sp.

NEMERTINEA—yellow nemertine, white nemertine.

POLYCHAETA—*Nereis* sp., + *Spirorbis* sp., + *Galeolaria caespitosa* Lamarck.

CRUSTACEA—+ *Chthamalus antennatus* Darwin, *Catophragmus polymerus* Darwin, *Balanus nigrescens* Lamarck, + *Tetraclita purpurascens* (Wood), *Chamaesipho columna* Spengler, + *Ligia australiensis* (Dana) sl., *Paridotea munda* (Hale), *Euidotea peronii* (M. Edwards), *Actaecia pallida* (Nich and Barn.), *Exoediceros maculosus* Sheard, + *Waldeckia chevreuxi* (Stebb.), *Elasmopus subcarinatus* (Haswell), *Amphithoe australiensis* Bate, *Hyale nigra* (Haswell) + *Hyale rupicola* (Haswell), *Calliopus* sp., *Ozius truncatus* (Edwards), *Leptograpsus variegatus* (Fabr.) sl. and l., *Plagusia Chabrus* (Linnaeus), *Cyclograpsus audouinii* (M. Edwards), + *Halicarcinus ovatus* (Stimpson), *Eriocheir spinosus* (M. Edwards), *Naxia tumida* (Dana).

MOLLUSCA—+ *Poneroplax albida* (Blainville) l. and sbl., + *Poneroplax costata* (Blainville) l. and sbl., *Haliotis roei* Gray, *Sophismelepas nigrata* Sowerby, + *Cellana tramoserica* Sowerby, + *Patelloida alticostata* Angas, *Actinoleuca calamus* Crosse, + *Chiazacmea conoidea* Qu. and Gaim., + *Notoacmea septiformis* Angas, + *Notoacmea scabrilirata* Angas, *Cantharidus pulcherrimus* Wood, + *Phasianotrochus bellulus* Dunker, + *Austrocochlea odontis* Wood, *Austrocochlea torri* Gray, + *Gibbula preissiana* Philippi, + *Subninella undulatus* Solander l. and sbl., *Subninella torquartus* Gmelin l. and sbl., *Phasianella ventricosa* Swainson, *Melanerita melanotragus* Smith, + *Melaraphe unifasciata* Gray sbl., + *Bembicium melanostoma* Philippi, + *Dardanula melanochroma* Tate, *Sabia conica* Schumacher (on other shells), + *Neothais textiliosa* Lamarck l. and sbl., + *Zemitrella yorkensis* Crosse, *Zemitrella semiconvexa* Crosse, + *Cominella eburnea* Reeve, + *Cominella lineolata* Lamarck, *Floraconus anemone* Lamarck, *Tethys norfolkensis* Sowerby, + *Siphonaria diemenensis* Sowerby, + *Siphonaria baconi* Reeve, + *Modiolus pulex* Lamarck, + *Kellia australis* Lamarck, *Hapalochlaena maculosa* Hoyle.

INSECTA—*Pseudanurida billitonensis* (Schött).

POLYZOA—red encrusting type sbl.

ECHINODERMATA—+ *Patiriella calcar* Lamarck, *Amphipholis squamata* Delle Chiaje, *Holothuria fuscocinerea* Jäger.

ASCIDIANS—*Boltenia australis* (*Pyura australis*) Herdman sbl., *Austrobotryllus* sp., sbl.

PISCES—*Myxus elongatus* sbl., *Scorpis georgianus* sbl., *Pseudolabrus psittaculus* sbl., *Pseudolabrus punctulatus* sbl., *Clinus perspicillatus, Syngnathus curtirostris.*

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THE CHARNOCKITIC AND ASSOCIATED ROCKS OF NORTH-WESTERN SOUTH AUSTRALIA
II. DOLERITES FROM THE MUSGRAVE AND EVERARD RANGES

By Allan F. Wilson

Summary

An analysis of an olivine bronzite-bearing dolerite and much optical data are presented in a study of several Precambrian basic dykes. Several interesting mineraliogical features are described, including duteric anorthoclase, some remarkable pigeonite and other pyroxene associations, strange skeletal olivine and pleochroic olivine. Courses of basic magma crystallisation are briefly discussed.

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By Allan F. Wilson *

[Read 8 July 1948]

Plate XVIII

Abstract

An analysis of an olivine bronzite-bearing dolerite and much optical data are presented in a study of several Precambrian basic dykes. Several interesting mineralogical features are described, including deuteric anorthoclase, some remarkable pigeonite and other pyroxene associations, strange skeletal olivine and pleochroic olivine. Courses of basic magma crystallisation are briefly discussed.

Contents

I. INTRODUCTION

Small scale basic intrusions of Precambrian age occur in the ancient rocks in the far north-western portion of South Australia. There are at least two types of such intrusions: (1) those of the *older group* are usually sill-like and occur only in the gneisses and granulites; they are often considerably metamorphosed.[1] (2) the *younger group* are mostly steeply dipping narrow dykes. Some of these have suffered metamorphism, but mainly in connection with the mylonitisation and epidotisation mentioned in a previous paper[2] (Wilson 1947, p. 209). Others, however, have been noted with the granoblastic recrystallised texture so commonly developed under thermal metamorphism.[3] Intrusions of this younger group traverse both the gneisses and the later charnockitic granodiorites.

* Department of Geology, University of Adelaide.

(1) *e.g.,* some of the amphibolites, etc., west of Mount Carruthers; north-east of Taljaritja; etc.

(2) *e.g.,* 1 mile north-east of Ernabella; west of Top Springs; 2 miles south of Inindi; etc.

(3) *e.g.,* in Trudinger Pass, near Oowallinna, etc.

Fig. 1 View of the platform from the sandy beach at low tide, showing the ledge, the channel, levels A and B and the sandy pool. (A composite photograph).

Fig. 2 The algal mixed-*Cystophora* association on the higher level of the platform. The gastropod in the centre of the field is *Cellana tramoserica*. (Photograph by I. M. Thomas).

Fig. 3 *Cellana tramoserica* and *Austrocochlea odontis* on the higher level of the platform. (Photograph by C. M. Eardley).

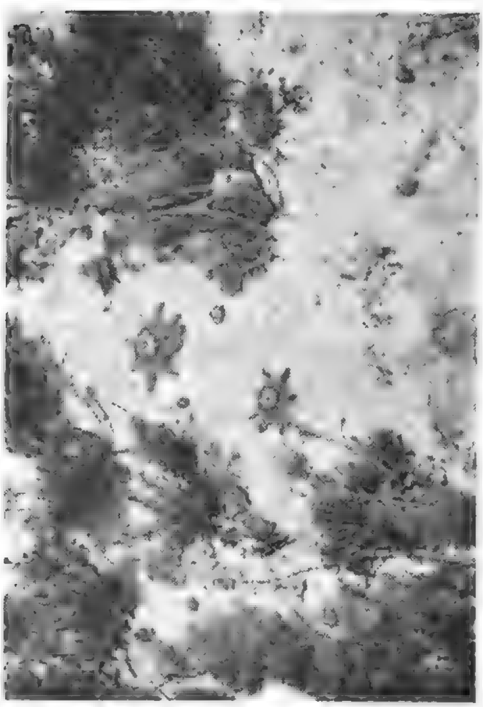


Fig. 1 *Patiriella calcar* and *Austrocochlea odontis* in the channel region. The alga showing is mainly *Cystophora uvifera*. (Photograph by Dr. T. Levring).

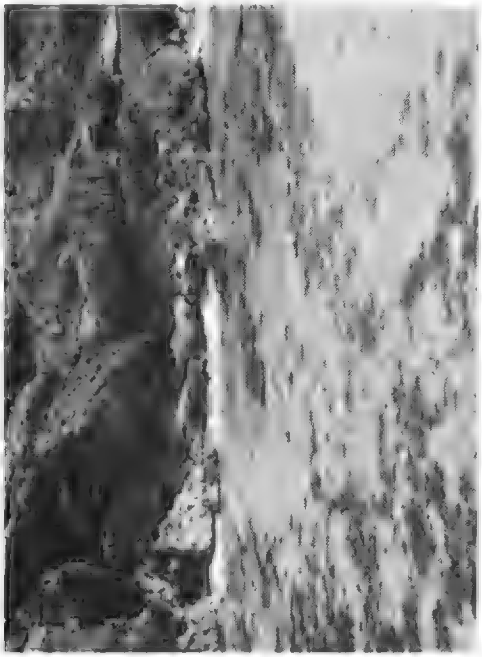


Fig. 2 View of the fallen rock area of the platform. *Bembicium melanostoma* is found on and near these rocks.

Fig. 3 View of the channel taken at very low tide from the outer edge of the platform and looking towards the sandy pool. (Photograph by I. M. Thomas).

Fig. 4 View showing the nature of the sub-littoral fringe.

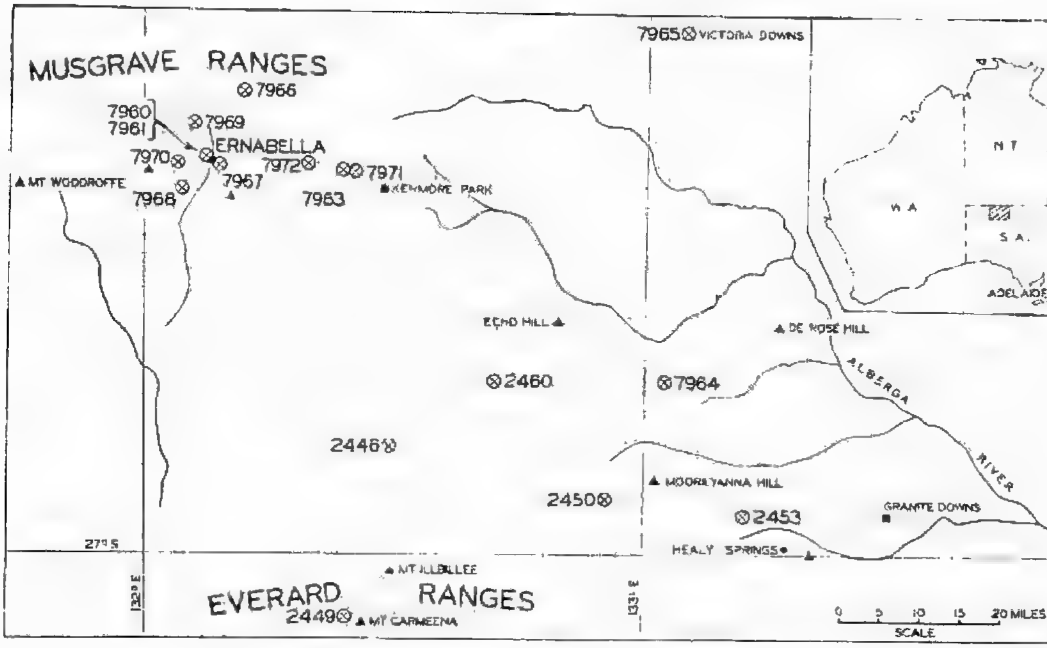


Fig. 1
Plan showing location of Dolerites described in text.

In this paper, however, only those basic dykes are dealt with which are unmetamorphosed and reasonably fresh. They belong to the "younger group" but nevertheless are considered to be of later Precambrian age (see Wilson 1947, p. 208).

The dark chocolate-brown weathered outcrops of these basic intrusions make prominent features on many of the desert-red hills of "granite" and gneiss. The dykes, themselves, however, are usually not large. A common size is about 300 feet long by 10 feet wide. Some are much more persistent, as, for example, the narrow six-mile-long dyke running from east of Naljawara through Ernabella to the region south-west of Mount Carruthers.

Such narrow dykes and the absence of flat-lying sills of the type so common, for example, in Tasmania and South Africa limit a petrological study, hence this paper will comprise, in the main, petrographic notes on the minerals and rock textures.

II. PREVIOUS WORK

Similar dyke rocks have been briefly recorded from many places in the Central Australian region. An excellent summary of the chief observations concerning these is given by Farquharson in an appendix to a Western Australia Geological Survey Bulletin (Talbot and Clarke, 1917). Streich (1892) recorded diorites and dolerites from several localities between the Everard Ranges and the Fraser Range. J. A. Thomson (1910) described interesting olivine norites and quartz dolerites from similar localities. Tate, Watt and Smith (1896) noted olivine dolerites, olivine norites, diorites, gabbros and fine-grained dolerites in the north-eastern MacDonnell Ranges. Basedow (1905) observed both diorites and dolerites in the Musgrave, Mann, Tomkinson, Everard and Ayers Ranges. He stated that diorite dykes are very plentiful, whereas the dolerites are less common. The present detailed work in the Musgrave Ranges has, however, failed to confirm this view. Dolerites (often olivine dolerites)

are much more abundant than the diorites in that region. Jack (1915) gives petrographic notes on several basic dyke rocks from the Everard Ranges, the south-eastern Musgrave Ranges and the country between the ranges. He recorded olivine gabbros, olivine dolerites, basaltic dolerite, etc.

In his summary, Farquharson (Talbot and Clarke, 1917, 144) concludes that the numerous basic dykes in this central region of the Australian continent show remarkably similar characters in the different localities. He himself describes norites, quartz dolerites and olivine dolerites.

III. MINERALOGY

The dykes under consideration are composed essentially of a basic plagioclase, subcalcic augite with or without olivine, bronzite and pigeonite. Magnetite, ilmenite and anorthoclase are often present. Quartz is absent except as an occasional xenolith or as a rare late magmatic mineral.

1. The Feldspars

(1) Plagioclase

In estimating the composition of the plagioclases, various methods were employed. The simplest and most satisfactory method was to make use of the abundant Carlsbad-albite twins. The two extinctions were measured after tilting on the universal stage to look directly down the composition plane of both pericline and the Carlsbad and albite twins. The extinction angles of X′ to trace of (010) were referred to a graph (labelled Pl. in figure 42) given by Chudoba (1933, 45), and those for the Carlsbad-albite twins were referred to a graph published by Kennedy (1947, fig. 2). Occasionally, as a check, full orientation procedure was carried out and the results plotted on the Wulff net. When this was done, it was found that the optic angle for the plagioclase consistently suggested a notably lower anorthite content than that indicated by the plot of the poles, e.g., (010) ⊥ X.

2 V	% An	(010) ⊥ X, % An.
−88 (core)	75	91
90	73	83
+84	67	60
+88	39	55
−86 (rim)	21 (?)	31

On the other hand, it was consistently found that the anorthite percentage as suggested by the optic axial angle (2 V) was notably higher than that indicated by the extinction angles (most extinction-angle methods give reasonably comparable results). An example of this is seen in the same rock (No. 7972).[4]

2 V	% An.	Ext. ∠ ⊥ Peric & (010)	% An. from Ext. ∠
−80	85	43½	81
−85	77	38½	71
+85½	68	30½	56

The plagioclase (though remarkably fresh) usually contains an abundance of dusty inclusions which decrease in abundance toward the more sodic rim of

(4) All numbers refer to specimens in the rock museum of the University of Adelaide.

which a narrow selvage is usually quite clear. These inclusions often give the thin sections a characteristic dark appearance.

Owing to the strongly zoned nature of the plagioclase, few measurements of refractive index were made. Further investigation of the optical and chemical properties of the plagioclases from this suite of dolerites should prove of value.

In almost all of the rocks examined, the plagioclases exhibit a considerable range of composition gradually changing from a basic core (usually a bytownite) through the average, which is basic labradorite, to a narrow rim of andesine and sometimes even basic oligoclase. In one rock (*7972*) the zoning is not gradual, but shows notable hiatuses (see pl. XVIII (c)). All zoning is normal—that is, from a basic core to a rim of less basic plagioclase. The average grain size of the feldspar lathes is about 1·2 mm. x 0·3 mm., with some in the sub-gabbroic types reaching 8 mm. x 2 mm.

(2) Anorthoclase

In many dolerites a fraction of one per cent. of anorthoclase occurs as a deuteric (late magmatic) crystallisation. It is often more plentiful in dolerites lacking in olivine and hypersthene (*e.g.*, *7971* and *7970*), but notable amounts (5·2% in *7964*, 3·4% in *2449*) occur in rocks among those with the largest percentages of olivine and other pyroxene. The mineral, though a plentiful accessory and easily distinguished, has apparently been overlooked by previous workers. Its refractive indices are lower than that of Canada balsam. It is colourless and clear with plentiful inclusions of apatite needles (pl. XVIII (d)). Included magnetite is often rimmed in part with biotite. Optical axial angle (where measured) varied from 2 V (–ve) = 59° to 42°. (In one thin section variation in 2 V has been as much as 52°–42°.) Plots of the cleavage poles appear in fig. 2.[5] Neither "cross-hatching" nor perthitic intergrowths was observed even under high power magnification. The mineral is triclinic, not monoclinic.

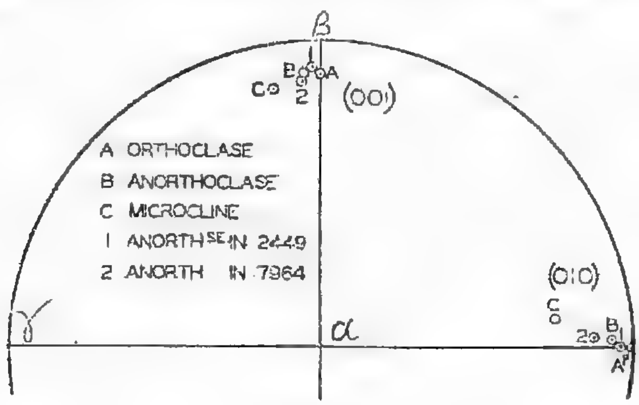


Fig. 2

Part of Stereogram showing relation of poles of (001) and (010) of Anorthoclase in two Dolerites to those of Orthoclase, Anorthoclase and Microcline (after Emmons 1943, pl. XII, No. 7).

2. The Pyroxenes

(1) The Orthopyroxenes

Orthopyroxene is usually, though not exclusively, confined to the olivine dolerites. There are many olivine dolerites, however, lacking that mineral.

[5] In certain South African dolerites some interstitial "soda orthoclase of low axial angle" was present (Walker, Poldervaart, 1942, 131).

Owing to the prevalent zoning, the composition was estimated from the measurement of optic axial angles. This is, of course, not as accurate as R.I. estimation, but sufficient for the purposes of this review. Poldervaart's suggested nomenclature of the orthopyroxenes is used, as also is his chart of optical properties and chemical composition (Pold. 1947, 167).

The most magnesic orthopyroxene is an *Enstatite* (OF. 8%) with 2 V (+ve) = 83° which occurs plentifully as clear colourless cores of a pleochroic bronzite (OF. 16%) with 2 V (–ve) = 81°, the whole pyroxene being enclosed poikilitically by large labradorites in a coarse dolerite (No. 7964).

Enstatite (OF 9%) with 2 V (+ve) = 84° also occurs rarely in No. 7970 as small irregular cores of a zoned pigeonite. *Bronzite*—The most ferriferous orthopyroxene is still magnesia rich, and is a bronzite (OF. 22%) with 2 V (–ve) = 71°. The most common orthopyroxene has a weak pleochroic core of bronzite (about OF. 14%) which grades into a strongly pleochroic rim of bronzite (about OF. 20%). The common grain size is 1 mm. x 0·4 mm., but in some (*e.g.*, 7961) the bronzite occurs as elongated crystals up to 4 mm. x 0·4 mm. Bronzite often has a patchy extinction caused by ex-solution of lime (see p. 199), or a fine lamellar twinning || (010) probably caused by deformation during crystallisation.

(2) The Clinopyroxenes

Three main varieties of clinopyroxene are present, *viz.*, augite, subcalcic augite and pigeonite. The nomenclature suggested by Poldervaart (1947 (a), p. 161), is adopted, which subdivides the clinopyroxenes primarily on optic axial angle. Thus those with 2 V exceeding 45° are termed *augites*, those with 2 V between 45° and 30° are *subcalcic augites*, and those with 2 V less than 30° are *pigeonites*. In pigeonite, the optic plane may be parallel or perpendicular to (010).

It is often only possible to distinguish the three clino-pyroxenes by measurement of the optic axial angle, for colour and pleochroism, habit, refractive index and often double refraction are usually very similar. Moreover, the orthopyroxenes (and even the olivines in some cases) present similar difficulties. Hand-picking of grains from crushed samples of rock was thereby rendered tedious. The only practicable way therefore to obtain reliable refractive index data was to first determine 2 V and Z∧C on a grain "*in situ*" in an uncovered slide (mounted in glycerine on the universal stage), then to dig out that grain, and by immersion methods, to estimate its refractive indices in sodium light.

The curves of Deer and Wager (1938) were used to estimate the composition, using 2V in conjunction with the γ index. Data for Z∧C were carefully collected and may assist in amending Tomita's charts (1934) which attempt to relate Z∧C to composition. These charts have been found in many places erroneous. Z∧C was always read from a sterographic plot of the optic elements and is probably as accurate as ± 1° for most of the well cleaved or twinned augites and most subcalcic augites. Z∧C for the pigeonite was found difficult to estimate better than about ± 3° or 4° owing to the prevalence of poor cleavage and lack of twinning. Details of these three clinopyroxenes:—

Augites. $\gamma = 1{\cdot}69\text{-}1{\cdot}705$; 2V (+ve) 52°-45°; Z∧C = 42°-37°; optic axial plane || (010); twinning rare; colourless to extremely faint green; non or very weakly pleochroic. Habit: subhedral up to 1·4 mm. x 0·8 mm., usually 0·3 mm. x 0·3 mm.; as cores of crystals of sub-calcic augite into which the augite commonly merges.

Subcalcic Augites. $\gamma = 1{\cdot}69\text{-}1{\cdot}725$; 2V (+ve) = 45°-30°; Z∧C = 41°-36°; optic axial plane (010); twinning uncommon, usually on (100); colourless or very pale green and non pleochroic, or pinkish fawn and strongly pleochroic.

X = faint rusty pink, Y = faint fawn, Z = very faint green, X > Y > Z. Habit: the most abundant pyroxene; subhedral, subophitic or strongly ophitic crystals, often strongly zoned and may form perfect link between augite and some pigeonites (q.v.); grain size very variable (1·3 mm. x 0·4 mm. to 0·1 mm. x 0·1 mm.); refractive index, double refraction usually increase, whereas 2 V and Z ∧ C decrease regularly toward the border zones of the subcalcic augites.

Pigeonites: $\gamma = 1{\cdot}682$; 2V (+ve) = 20°-0° (optic axial plane ⊥ (010)); $\gamma = 1{\cdot}730$; 2V = 0°-30° (optic axial plane ∥ (010)); twinning extremely uncommon; colourless, or moderately pleochroic in faint pinkish fawns and greenish tones similar to the more ferriferous subcalcic augites. Habit: never abundant but occurring with one or more of the other pyoxenes (depending on the variety of pigeonite) and with or without olivine; late crystallisations often strongly ophitic, with other types subhedral and strongly zoned; grain size very variable but usually somewhat smaller than the accompanying clinopyroxenes.

Present data indicate several unusual occurrences and associations, and, as far as can be ascertained, nothing quite comparable has been described from elsewhere. Pigeonite occurs in seven dolerites, and some of the properties and associates are set out in Table I.

From this it is apparent that the mode of occurrence of the pigeonite differs in all seven rocks. The probable significance of this is discussed in the section on the petrology.

2. Olivines

Olivine occurs in a large number of dykes. There seems to be no rule regarding its occurrence, as for instance, in certain of the Karroo dolerites, where the mineral is present in all sills which do not contain orthopyroxene. (Walker and Poldervaart, 1942, 135).

In the Musgrave and Everard Ranges, olivine is often found with an orthopyroxene which at times encloses it.

The olivine shows a remarkably constant composition (as deduced from measurements of optic axial angle which varies from 2 V (+ve) = 88° to 2 V (−ve) = 85 (2 V (−ve) = 87° is common). This suggests a range in composition from a forsterite (Fa 7%) to a chrysolite (Fa 23%).(6) The mineral is usually colourless, cracked but remarkably fresh and free from inclusions. In two rocks (7965 and 2460) there is a marked pleochroism (X = blue-grey, Z = fawn grey; X > Z). Some microscopic particles, possibly iron ore, are orientated in the plane ⊥ Z, but are not thought to account for the marked pleochroism.

In 7964, 2446, and especially in 2449, the olivine contains plentiful inclusions of iron ore.

The mineral usually occurs as subhedral crystals about 0·6 mm. x 0·4 mm., but crystals up to 1·6 mm. x 1·6 mm. occur. In 7965 olivine of essentially the same composition (Fa 21%) is found enclosed in augite, and also as small ophitic particles of late formation (0·1 mm. x 0·1 mm.).

In 7967 (and to less extent in 7968 and 7969) rare skeletal crystallisations occur in association with an unusual "plumose" pyroxene (see pl. XVIII, a; and description on page 194).

(4) Minor Constituents

Iron ore is present in varying amounts in all rocks. This constituent appears to be mainly *magnetite* with some *ilmenite* in places intimately associated. The grain size is very variable, attaining 0·5 mm. x 0·3 mm., but grains 0·3 mm. x

(6) Using the proposed classification of Deer and Wager (1939).

0·2 mm. are common. In many rocks the primary magnetite is often concentrated with the small patches of anorthoclase and secondary dusty iron ore.

Chromite (?). A few grains of the dull black mineral is included in magnetite in most rocks.

Pyrite and Pyrrhotite occur sparingly in most rocks, and are associated with the other iron ores.

Amphibole. No primary amphibole is present but a strongly pleochroic variety occurs in small amounts in the patches of deuteric material in No. 7971. Here it has been formed in part by the alteration of some of the pyroxene. X = yellow-green, Z = deep blue-green; $Z \wedge C$ = about 15°.

Biotite. This mineral is present in almost all rocks as small flecks associated with the iron ore and usually with deuteric anorthoclase. Some also occurs as flecks in all the earlier minerals (otherwise perfectly fresh) and apparently out of reach of later solutions. Common size is 0·3 mm. x 0·2 mm. X = yellowish. Y = Z = dark chestnut brown.

Apatite occurs only as long colourless rods in the deuteric anorthoclase. In 7971 these rods are up to 2 mm. in length.

Iron Spinel is rare but occurs as small deep green isotropic grains associated with magnetite, chromite and olivine, *e.g.*, 7963.

Quartz was noticed in only two rocks. In 7971 it comprises about a half of the 3-4% of the acidic residue. It is distinguished from the anorthoclase and plagioclase by its clarity, higher refraction and double refraction. It gives a normal uniaxial (+ve) interference figure.

In the other rock (7972, q.v.) a xenolith of quartz occurs surrounded by a strong rim of subcalcic augite (the dyke injects acidic gneisses).

Chloritic and Serpentinous and other alteration products are present in minor amounts. The rocks, however, are unusually fresh.

IV. PETROGRAPHY

For descriptive purposes the dolerites have been classified on the following features:

(1) presence or otherwise of olivine;
(2) presence or otherwise of orthopyroxene;
(3) texture.

A. Olivine-bearing Dolerites

(1) Olivine Orthopyroxene-bearing Dolerites:
- (a) those with *coarse poikilitic texture* (7964, 2446);
- (b) those with *subophitic texture* (7963, 2460, 2449);
- (c) those with *ophitic texture* (7960, 7961).

(2) Olivine-bearing Dolerites (*i.e.*, free from orthopyroxene):
- (a) those with *coarse poikilitic texture* (7968, 7969);
- (b) those with *subophitic texture* (7966);
- (c) those with *ophitic texture* (2453, 7965, 2450);
- (d) those with an unusual *"plumose" texture* (7967).

B. Dolerites (*i.e.*, free from Olivine)

(1) Orthopyroxene-bearing Dolerites:
- (a) those with *ophitic texture* (7970).

(2) Normal Dolerites (*i.e.*, free from both Olivine and Orthopyroxene):
- (a) those with *sub-ophitic texture* (7972);
- (b) those with *ophitic texture* (7971).

A. Olivine-bearing Dolerites

(1) Olivine Orthopyroxene-bearing Dolerites

(a) *Olivine Orthopyroxene-bearing Gabbroic Rock with coarse Poikilitic Texture.*[7]

1. *No. 7964* is a remarkable fresh dark grey medium-grained gabbroic rock. It was collected from a large dyke on the new "Royal Mail" track (Feb. 1944), 14 miles east of De Rose Hill hut.

In thin section the gabbro appears unusually well crystallised. The olivine, orthopyroxene and clinopyroxene form euhedral crystals which are set poikilitically in large tabular crystals of plagioclase up to 6 mm x 2 mm.

A summary of the main mineralogical data is included in Table II.

The *Plagioclase* is well twinned on the albite and pericline and occasionally on the Carlsbad laws. Its composition is unusually constant (An 65%) but gives way abruptly to a clear anorthoclase. This mineral is in strong relief to the labradorite which, though perfectly fresh, is often a pale chestnut brown on account of myriads of tiny inclusions of iron ores (?). The *anorthoclase* has all refractive indices less than that of Canada balsam, but 2V (–ve) varies from 51° in one case to 59° in another (see fig. 2). Associated with the anorthoclase are the usual acicular apatite needles and biotite. The anorthoclase, which makes up 5·2% of the rock, forms clear-cut boundaries with the labradorite (see pl. XVIII d).

The *orthopyroxene* occurs as beautifully formed crystals. The cores are of a colourless enstatite (OF 9%) and all gradations are seen into the strongly pleochroic rims of bronzite (OF 16%). The orthopyroxene contains no inclusions of importance. The extinction is at times irregular and suggests the beginning of the lamellar intergrowth mainly, so well seen in 7963 (see p. 199). The *monoclinic pyroxene* is represented by non-pleochroic very pale green-grey augite. The borders of some of the crystals begin to show a weak pleochroism in greens and pinks, but it is the double refraction and extinction angle ($Z \wedge C =$ 36-37°) which serve to distinguish the ortho- from the clinopyroxene in reconnaissance. Magnetite is included in the olivine in two ways, *viz.*, as particles of iron ore crystals scattered irregularly through the mineral, and as myriads of tiny orientated iron ore inclusions.

2. *No. 2446* is a "dark-coloured rock of medium grain with the normal weathered surface". It occurs as "a large east and west dyke 15½ miles north of Mount Illbillie" (which is the most prominent hill in the Everard Ranges). The rock has been briefly described by Jack (1915, 18), and the dyke is figured in the text.[8] His description is deficient in that the most abundant pyroxene (orthopyroxene) has been mistaken for a clino-pyroxene, and the anorthoclase has been overlooked. The rock in thin section is very similar to No. 7964 described above. The crystals of pyroxene are not quite so well crystallised, however, and there may be a little more clinopyroxene present than in 7964. The optical properties of the minerals, however, are almost identical in the two rocks, even though rock No. 2446 was collected 35 miles from 7964. Both 7964 and 2446 contain minerals more magnesia-rich than most of the dolerites. Even though they have apparently cooled for a longer period, lamellar intergrowth so

[7] This rock is strictly of gabbroic texture but is treated with the dolerites because of its obvious relations.

[8] R. L. Jack briefly described rocks from several basic dykes in the region of the Everard and Musgrave Ranges. These appear in the report on his geological reconnaissance in the area (Jack 1915). The original thin sections described by Dr. Jack are still available for examination, but unfortunately the hand specimens are missing.

typical of many bronzites (*e.g.*, those of *7961*, *7970*, *7963*, etc.) is absent. A "shadowy" extinction is, however, occasionally present. It is probable that at no time did early pigeonite form.

(b) *Olivine-Orthopyroxene-bearing Dolerites with Subophitic Texture.*

1. *No. 7963* is a fine-medium holo-crystalline very dark grey rock. It occurs as a steeply dipping east to west dyke cutting gneissic granitic charnockites near a tiny rock hole a furlong north of the track about 19 miles from Ernabella toward Kenmore Park in the eastern Musgrave Ranges.

In thin section the rock appears as a remarkably fresh olivine-bronzite-bearing dolerite with only a very poor ophitic texture. It has apparently cooled fairly slowly and in fairly "dry" conditions.

The results of a chemical analysis and calculation of the norm and mode are set out in Table III, and a summary of the main mineralogical data is included in Table II.

It is apparent at once that the normative and modal minerals are at considerable variance. It is suspected that this is largely due to a high alumina content of the clinopyroxene. This cannot be readily proved, however, for the pyroxenes are all so similar in general appearance and properties that it is too difficult at present to attempt a mineral separation with a view to analysis. Calculations, based on estimated relative proportions of the heavy minerals and working back from optical data of the plagioclase, olivine and orthopyroxene, have indicated that the clinopyroxene probably contains about 10% Al_2O_3. Some Al_2O_3, however, may be held in the orthopyroxene or even in the olivine.

Frankel (1943, 20) noted that some analyses (similar to that under discussion here) showed "little similarity between the norms and modes by volume, and still less between the former and mode by weight. Bowen (1928, 142) points out that the norm does not take into account any alumina which may be in the pyroxene, and thus false values for anorthite and consequently for pyroxene are obtained".

The relative percentages of MgO (notably high for a dolerite), CaO and Al_2O_3 are unusual, which fact has made selection of comparable analyses difficult. A few dolerites from the adjoining region in Western Australia have been analysed but most of these are quartz-dolerites. The olivine dolerites from that State are usually much lower in MgO and also differ in other respects. No. 4, in Table III, is an example of one such dolerite. A search through the available literature has shown that the most comparable rocks are probably those described by Frankel from the Karroo, and Ferguson from Rhodesia. The analyses with their norms appear as Nos. 2 and 3 in Table III.

The modal percentage (by volume) of pyroxene in *7963* is given as 45·6%. The main pyroxene is a non-pleochroic faint yellowish-green *augite* with 2V (+ve) = 48°, $Z \wedge C = 39°$. A few simple twins are present (‖ (100)). Commonly fan-like bunches of crystals occur which presents an irregular extinction in places, rendering difficult the accurate measurement of 2V and $Z \wedge C$. This extinction is a type of "polarisation cross" with the cross indicating an extinction angle ($Z \wedge C$) of about 38°. The refractive index (γ) = 1·708 ± ·002. It is probable that this is the pyroxene which has the high alumina content discussed above.

Next in importance is *bronzite* which comprises about one-quarter of the total pyroxene (45·6%). It is pleochroic in pinks and faint green-greys and has 2V (−ve) = 71°, which suggests an approximate composition OF = 22%. The extinction is usually straight and its double refraction is lower than in the clinopyroxenes.

The mineral often encloses olivine (Fa 18%) and is itself sometimes partly enclosed by the non-pleochroic (or weakly pleochroic) clinopyroxene. A patchy extinction tending to grade into a fine lamellar intergrowth parallel to (010) is often seen in suitable sections.

The proportion of the third pyroxene (a *subcalcic augite*) is difficult to estimate. It probably makes up, however, between one-fifth and one-sixth of the total pyroxene. At first sight confusion could easily arise as the pleochroism is almost exactly the same as that of the bronzite. The only certain method of distinction is that of measurement of the optic axial angle ($2V$ (+ve) $= 40$-35°), although the large extinction angle ($Z \wedge C = 38^\circ$) and higher double refraction assist to identify the clinopyroxene in reconnaissance.[9] This pleochroic clinopyroxene is similar in some respects to that in No. 7968, where it forms a continuous link between the early non-pleochroic augites, weakly pleochroic subcalcic augites and more iron-rich pigeonites of later crystallisation.

No pigeonite ($2V(+ve) < 30^\circ$) was noticed, although a careful search was made. "Nearest approach" to a late pigeonite is probably the pleochroic subcalcic augite described above. No "early" pigeonite can be expected owing to the presence of the lamellar intergrowth in the bronzite, which intergrowths have been formed by an inversion (?) of a pigeonite during the cooling process. Had the cooling been accelerated some early pigeonite may have remained in a metastable condition, as in the ophitic dolerite No. 2453.

This rock contains much more *olivine* than most of the other dolerites. It is remarkably fresh and clear.

Of the 4% *accessories*, the iron ores are the most important. In order of importance they are magnetite, ilmenite, chromite, and pyrite. About 0·5% of brown *biotite* is present. It is associated with the iron, but no *anorthoclase* was noticed.

The *plagioclase* varies in composition from bytownite (An 82%) to labradorite (An 67%). Some edges of the plagioclases are somewhat more sodic. The average is probably bytownite (An 72%). The most common twin laws represented are albite, Carlsbad and pericline. The mineral is somewhat clouded, not by alteration products but by dusty inclusions of (?) magnetite (*cf.* 7964, 7961, etc).

2. *No. 2449.* Nos. 2449 and 2460 show the subophitic texture better than the more basic rock No. 7963. Nos. 2449 and 2460 were collected by R. L. Jack (1915, 19), and briefly described by him as Nos. 14-3-48 and 14-3-23 respectively.

No. 2449 is a "dark-coloured rock, fairly coarse-grained and weathering to a reddish surface". The rock occurs in a "large dolerite dyke forming the cap" of a black hill two miles west-north-west from Mount Carmeena in the Everard Ranges, where the dyke cuts granite. The dyke strikes approximately east to west and dips about 35° north (a photograph of the dyke is given facing page 18 of Dr. Jack's account).

In thin section it appears as an olivine orthopyroxene-bearing dolerite. A summary of the main mineralogical data is included in Table II. The pleochroic mineral is not augite (except only on some border zones) but a bronzite (*cf.* Jack 1915, 19). The biotite is always "associated with the magnetite" it is true, but in this rock is due to a late magmatic (deuteric) alteration of the mag-

[9] Johansen (1937, 3, 212) has emphasised that orthopyroxenes can have an inclined extinction in certain sections. Great care had to be taken in several of the dolerites here described because of the presence of both an ortho- and clino-pyroxene which showed similar pleochroism.

netite and sometimes pyroxene. Colourless *anorthoclase* with many colourless needle-like inclusions of apatite comprise the matrix of the biotite. No quartz is present.

Typical masses of anorthoclase have 2V (–ve) = 52° and all refractive indices below that of Canada balsam. A plot (⊥ X) of the (010) and (001) cleavages is indicated in fig. 2. Another good area of the mineral has 2V (–ve) 42° ± 2°. No twinning is shown even in the highest magnification. The mineral has very low double refraction.

A notable feature of the *olivine* (Fa 21%) is the abundance of squat needles of (?) magnetite inclusions (especially in the cores). The mineral is non-pleochroic (contrast Nos. 2460 and 7965).

The *bronzite* is more ophitic than the subcalcic augite. The most ferriferous bronzites occur in this rock (bronzite, OF = 22). It occasionally shows a patchy extinction but no notable lamellar intergrowths. Neither early nor late pigeonite is present.

Though fresh, the *feldspar* is stained a dirty brown with minute dusty inclusions. As the outermost zones of the plagioclase are reached this staining is less marked. The composition varies gradually from cores approaching a bytownite of An 75% to rims of andesine (An 44% or even less). There is often gradation from this last zone to the anorthoclase in such a way as to suggest the latter's crystallisation from the residual liquors.

3. *No. 2460* is "a very finely crystalline dark grey rock weathering to a reddish surface". It occurs as a "dyke in a swamp on track, 23½ miles north 65° west from Moorilyanna Hill", and is in the region between the Musgrave and Everard Ranges.

In thin section it appears as an olivine orthopyroxene-bearing dolerite. Dr. Jack (1915, 19) makes mention of an earlier generation of augite which is distinctly pleochroic. On investigation this earlier generation "augite" proves to be a typical *bronzite* comparable with that in No. 2449.

It makes up approximately one-half of the total pyroxene. The bronzite encloses olivine (Fa 12%) but is itself enclosed by the non- or weakly-pleochroic subcalcic augite. It is readily distinguished from the clinopyroxene by its lower double refraction, pleochroism and common straight extinction. The mineral only occasionally shows a patchy extinction. Neither early nor late pigeonite was observed.

Features of this rock are the pronounced development of *dark brown dusty inclusions* in the bytownite and labradorite, and the pleochroism of the *olivine* (Fa 12%) in blue-greys and fawn-greys. No. 7965 is another rock showing a pleochroic olivine (q.v.).

(c) *Olivine Orthopyroxene-bearing Dolerites with Ophitic Texture.*

Nos. 7960 and *7961*. Dolerites belonging to this group are best represented by Nos. 7960 and 7961, which were both taken from the prominent dyke which cuts the charnockitic granodiorite on the west of the main valley between Ernabella and Mount Carruthers in the eastern Musgrave Ranges. The dyke itself is several miles long and is probably continuous with a similar dyke to the south of Ernabella (see main map, Wilson 1947). This dyke is the most important of a poorly developed set which strike more or less north and south with a shallow dip to the east.[10] This particular dyke is only about 15 feet thick, but is, nevertheless, one of the largest dykes in the eastern Musgrave Ranges.

[10] Most of the dolerite dykes of the Musgrave Ranges strike south of west and dip steeply 60°-70° toward the south.

In hand specimen the character of the dyke rock varies from a medium to coarse-grained very dark grey dolerite. Both types appear remarkably fresh. A summary of the main mineralogical data is included in Table II. The finer phase (7960) was taken from near the bottom contact, whereas the coarser phase (7961) was collected near the middle of the narrow low dipping dyke. Little differentiation has taken place.

The coarser phase is apparently somewhat richer in iron and volatiles, as is revealed in both modal percentages and optical properties of all three pyroxenes, and the presence of a little late pigeonite which is absent from 7960. The plagioclase is a slightly more sodic variety of labradorite. Bronzite commonly has excrescences of a subcalcic augite, which often show a peculiar fan-like or stellate form with shadowy extinction (*cf.* that seen in 7963).

In the modal percentages, an accessory amount of a soda feldspar is included with the plagioclase. The mineral is similar to that described from rocks numbers 7964, 7966, etc., where it was determined as an anorthoclase. In this dyke the amount varies from about 2% in No. 7960 to about 4% in No. 7961. The anorthoclase is both interstitial and partly replacing the outer more sodic zones of the plagioclase. No quartz has been determined but long apatite (?) needles are plentiful as inclusions. A pleochroic (yellow to brown) biotite and dusty magnetite are usually associated with these patches of anorthoclase, which is apparently mainly of deuteric origin.

Primary magnetite and pyrite are plentiful, but the percentage of total iron ores is increased by the dull black material liberated on alteration of some of the olivine and pyroxene.

The coarse phase (7961) contains much more bronzite than the finer phase (7960). This may represent the inversion to bronzite of the early pigeonite (see p. 199). The presence of a continual gradation from the subcalcic augites into the late pigeonites seems in this rock to be assisted by the somewhat higher concentration of late liquors (as indicated by the coarser grain size and increased percentage of deuteric anorthoclase).

(2) Olivine-bearing Dolerites (*i.e.*, those free from orthopyroxene).

(a) *Olivine-bearing Dolerites with coarse Poikilitic Texture.*

1. *No. 7968* is a dark grey medium-grained rock taken from the most southerly of several parallel dykes which cut the south-west tip of the large mass of charnockitic granodiorite situated about two miles west-north-west from Palpatjara, which is three miles south of Ernabella. The dyke, which strikes toward the west-south-west and dips 65° toward the south, is figured in a previous paper (Wilson 1947, pl. II, fig. 4).

In thin section this fresh rock appears holocrystalline with pyroxene and olivine mainly set poikilitically in relatively large (max. 3·6 mm. x 1·2 mm.; average 2·0 mm. x 1·0 mm.) crystals of labradorite. A summary of the main mineralogical data is included in Table II.

The *plagioclase* (42·5%) is usually clear but occasionally has a pale brown dusty patch due to tiny inclusions. The mineral is so poorly twinned (mainly on the albite and pericline laws) that no easier method of estimating its composition was available than to use the plotting the poles of the cleavages on a stereogram. Zoning is not prominent and the feldspar has a fairly constant composition of An 67% ± 3% (*i.e.*, a basic labradorite). No anorthoclase was detected.

The *pyroxene* (48·1%) occurs in two generations. The larger crystals (up to 1·3 mm. x 0·4 mm., but average 0·8 mm. x 0·6 mm) are commonly subhedral, clear and colourless (but very pale brownish pink in some outermost zones).

The cores have $2V = 52°$ and $Z \wedge C = 36°$, but there is a gradual decrease towards the rims to pigeonite with $2V = 19°$, $Z \wedge C = 30°$, optic plane ‖ (010) (see fig. 3 (a)). The strange "polarisation cross extinction effects are commonly present.

The smaller set of pyroxene crystals (a late crystallisation) are virtually colourless, although some show a very pale pink when parallel to X. They are ragged or sphenoid in shape, and have an average grain size of 0·15 mm. x 0·05 mm. The grains are too small, and extinction too erratic to do accurate optical determination on most grains "*in situ*", but of those studied, many are pigeonite with variable optic axial angle (one with 2V (+ve) as low as 17°; optic plane ‖ (010). $Z \wedge C$ could not be determined as there are neither suitable cleavages nor twinning.

The *olivine* (6·6%) which contains about 24% fayalite molecule is fairly clear and colourless, but along the plentiful cracks secondary magnetite and serpentine have formed. The mineral is at times subhedral but commonly holey, and on rare occasions simulates some of the "skeletal" olivine of rock No. 7967 (q.v.).

Accessories (2·8%) comprise mostly some primary magnetite, secondary magnetite and serpentine, with a little pyrite. Neither anorthoclase nor bronzite was observed. Though poikilitic and containing relatively coarse plagioclase, the name "dolerite" is preferred to "gabbro" because of the grain size and characters of the finer set of pyroxenes and its affinities with the main suite of dolerites.

The apparent absence of both bronzite and early pigeonite but the abundance of a magnesic clinopyroxene is interesting. It is possible that the conditions which allowed this poikilitic form (so uncommon in this area) to develop were unsuited to the formation of either an orthopyroxene or early pigeonite.

2. *No. 7969* is dark grey medium-grained rock occurring as a small east-west dyke cutting the gneisses near the junction with the large charnockitic granodiorite mass to the east in the creek beds one mile west of Top Springs (5 miles north-north-west of Ernabella).

In thin section this rock shows similarities to two widely separated east-to-west dykes (Nos. 7968 and 7967). The *plagioclase* (up to 6 mm. x 2 mm., average 2·2 mm. x 0·8 mm.) is a clear basic labradorite and comprises approximately 50% of the rock. It encloses poikilitically the pyroxenes and very similar to those described above in No. 7968, except that the smaller set (average 0·15 mm. x 0·05 mm.) tend in a few places toward a crude development of the plumose texture so pronounced in No. 7967. The grains are very small but no pigeonite was definitely proved (contrast 7968) although it is suspected. Neither bronzite nor early pigeonite was observed. Olivine (often in part decomposed) and magnesia-rich clinopyroxenes are plentiful (*cf.* 7968).

(b) *Olivine-bearing Dolerites with Subophitic Texture.*

1. *No. 7966* is a dark grey dyke rock occurring on the eastern flank of Razor Hill, 11 miles north-north-east of Ernabella. It cuts the charnockitic granodiorite just inside its junction with the gneisses. In thin section the rock is seen to have undergone a considerable amount of alteration by (mainly) deuteric solutions. This has resulted in a precipitation of dusty iron ore and formation of an amphibole, biotite and anorthoclase. A summary of the main mineralogical data is included in Table II. The percentage (58·1) for *plagioclase* includes 4-5% *anorthoclase* similar in optical properties and relations to that described elsewhere (*e.g.*, 7964). Usually the cores of the much zoned plagioclase are quite a dark shade of brown owing to myriads of tiny dusty inclusions of iron ore (?). The more sodic outer rims show fewer dusty inclusions, and the

anorthoclase is perfectly clear apart from the usual few needle inclusions of apatite (?). The plagioclase often has a core with composition about An68%, the outer zones ranging through the average type (a labradorite An65%) to a sodic Andesine (An34%) or even less, as it gives way in many cases to the anorthoclase.

The pyroxene is a strongly pleochroic relatively ferriferous variety of *subcalcic augite* and in places gives way to a *pigeonite* (optic plane || (010). Plentiful clouds of magnetite (?) dust are often seen scattered at random through the pyroxene (contrast the regular zones of "dust" in the pyroxenes of No. 7970). The *olivine* (Fa = 19%) is plentiful (6·3%), but much has been altered to serpentinous material and iron ore (the original rock proper contained about 8% olivine). A little of the pyroxene has often been altered to a biotite and pale green amphibole, but most of the deuteric products have been formed from the iron ores.

Along a few lines of fracture abundant magnetite has been liberated from the pyroxenes. These fractures occurred after the main period of deuteric alteration, as rarely is the liberated iron ore surrounded by biotite.

The most peculiar feature of this rock is the absence of bronzite but the presence (though rarely) of a *small pigeonite core* in some of the subhedral crystals of subcalcic augite. The pigeonite has a high 2V (27°-30°) with optic plane || (010) and grades (with no break) into the surrounding subcalcic augite (2V = 30-40°).

(c) *Olivine-bearing Dolerites with Ophitic Texture.*

All olivine dolerites yet examined which lack in bronzite and have a notable ophitic texture contain a pigeonite.

1. *No. 2453* is a "very dark grey rock with reddish-brown weathered surfaces". It occurs "7 miles north-west of Healy Springs" on the track between Indulkana and Moorilyanna Hill. The rock has been briefly described by Dr. Jack (1915, 19) as No. 14 - 3 - 9. The important mineral *pigeonite* is omitted from his description. This is not surprising, as both the subcalcic augite and pigeonite are very similar in all obvious optical properties and only easily distinguished by estimation of optic axial angles.

The *subcalcic augite* shows ophitic texture exceptionally well with the ragged plates averaging 2·5 mm. x 1·5 mm. With this occurs the *pigeonite* (¼ (?) of the total pyroxene). This pigeonite differs from some of the pigeonites described in other rocks (*e.g.,* 7970, 7961, 7968) in that the optic axial plane is perpendicular to (010) and there is a marked break between the two minerals when viewed under crossed nicols. Both minerals are ophitic but the pigeonite less so than its host, the *subcalcic augite*. Fig. 3 (b) indicates the strange variation in optical properties from the pigeonite to the rim of the enclosing clinopyroxene.

The pigeonite itself appears to have little variation (relatively) in optic axial angle (2V (+ve) = 14° to 22°; $Z \wedge C = 39°$; optic axial plane ⊥ (010)). This probably indicates that the trend of the non-pigeonitic clinopyroxenes is upwards toward the "Hump" of Hess' "course of crystallisation" curve (see p. 197, and fig. 4).

The absence of *bronzite* is noteworthy. The conditions of cooling were apparently such that the early pigeonite at no time was able to invert to orthopyroxene.

The *olivine* which is more magnesia-rich than usual (Fa 11%) is not plentiful (2·2%). It is usually somewhat "corroded" and enclosed in the early pigeonite or other clinopyroxene. The mineral contains some dusty magnetite inclusions and is somewhat serpentinised.

The *plagioclase* (59·7%) is not nearly so variable in composition as usual. It is a labradorite (An62%). There is a small amount (0·4%) of a typical *anorthoclase*.

A summary of the main mineralogical data is included in Table II.

2. *No. 7965* is a dark grey rock taken from a prominent dyke at Victoria Downs Homestead, 65 miles east from Ernabella and 125 miles from the Finke railway siding in Northern Territory.

In thin section the rock presents a medium-grained ophitic texture. A summary of the main mineralogical data is included in Table II.

A striking feature of the rock is the *pleochroic olivine* (X = blue-grey, Z = fawn-grey). There are myriads of little inclusions of iron ore arranged ⊥ Z, and the possibility of these causing the "pleochroism" was investigated. It seems that the pleochroism is intrinsic. This is uncommon, especially in such a magnesia-rich olivine (Fa 21%).

The olivine began to crystallise first and continued to form (with much the same composition, viz., Fa 21%) to the end, where is occurs with the late pigeonite and subcalcic augites as small sphenoid particles only 0·1 mm. x 0·1 mm. No. 2460 contains a pleochroic olivine (Fa 12%), but its associates are different from those in this rock.

Augite and pigeonite together make up 32·5% (by volume) of the rock. Since both minerals exhibit the same pleochroism and both occur poikilitically the only easy method of distinguishing the two species is by an estimation of optic axial angle. The *pigeonite* usually occurs in somewhat smaller grains, has a low optic axial angle and very poor cleavage, therefore it was found impossible to definitely prove whether this species had its optic axial plane parallel or perpendicular to (010). The work done suggests, however, that it is ‖ (010). There is probably a continuous series between the lower optic axial angle subcalcic augite and these pigeonites (cf. No. 7968). This pigeonite usually occurs as small sphenoid crystals controlled by the poikilitic texture of the rock.

The *augite* varies widely in composition, as indicated by the fact that the optical properties vary from 2V (+ve) = 46°, $Z \wedge C = 42°$ through the mean of 2V (+ve) = 42°, $Z \wedge C = 41°$, to 2V (+ve) = 31°, $Z \wedge C = 37°$.

As stated above, there is probably a continuous series towards an almost "uniaxial" pigeonite.

There is also a little *pigeonite* of a different nature. It is enclosed by the augite, has 2V (+ve) = 19° with optic axial plane ⊥ (010). Thus this dolerite contains two pigeonites. The "early pigeonite" shows a break with the augites, but the later type shows no such break and probably forms a continuous series from the subcalcic augites.

No bronzite is present; conditions of crystallisation were apparently such as to prohibit inversion of the small amount of "early pigeonite".

The plagioclase is zoned with compositions estimated at bytownite (An72%) for some cores to basic andesine (An49%) for some rims. A basic labradorite (An68%) is common.

3. *No. 2450.* Dr. Jack (1915, 19) states that he collected this specimen "from a dyke six and a half miles S. 60° W. from Moorilyanna Hill", *i.e.*, about 18 miles west from the locality of 2453.

The general appearance of this rock resembles No. 2453. The ophitic texture, for instance, is similar to that of 2453. However, there are considerable and significant mineralogical differences. A summary of the main mineralogical data is included in Table II.

As in most rocks *olivine* was the first ferromagnesian mineral to crystallise, and it continued for some time. *No bronzite nor "early pigeonite"* is present,

and the next mineral to appear in the *augite* (2V (+ve) = 49°-45°) rimmed with subcalcic augite. The augite cores 2V = 49° with continuous gradations toward the rims of a subcalcic augite with 2V = 37°.

On some edges (never enclosed) occurs a *pigeonite*. It has 2V (+ve) ranging from 22° to 15° with optic axial plane perpendicular to (010) and hence usually shows a pronounced optical break with the main clinopyroxene. The change from the subcalcic augite to the pigeonite seems always to take place about 2V = 37°. Both pigeonite and subcalcic augite have well-developed ophitic texture and seem to have come out together at the end as the final crystallisation (see fig. 3(c)).

In 7965 a "late" pigeonite crystallised with the last subcalcic augite, but in that rock the pigeonite has the optic axial plane parallel to (010) and there is probably a continuous series between the two clinopyroxenes. Moreover, a pleochroic olivine (Fa 21%) is found in 7965 crystallising right through to the end and occurs as small ophitic sphenoids with the two clinopyroxenes.

In 2450 the variation in the composition of the clinopyroxene is shown by the gradual decrease in optic axial angle from 2V (+ve) = 49° to 37°. It is probable that the trend is along the "course of crystallisation" (see p. 199), beginning near the top of the hump and near the point reached by the clinopyroxenes of rock No. 2453.

Plagioclase is abundant (55%) and notably calcium-rich. It is well zoned with cores of bytownite (An82%) to rims of andesine (An46%), with an average of bytownite (about An75%). The plagioclase is much clearer than usual, with only a few cloudy patches of inclusions.

Anorthoclase is present but rare, and there is a little subhedral original *magnetite* as well as the secondary dusty iron ore. Some serpentinous material is present as an alteration of some pyroxene and olivine.

(d) *Olivine-bearing Dolerites with an unusual "Plumose" Texture.*

There are several fine-grained dark grey dyke rocks which cut the north-west slopes of the charnockitic granodiorite hills 1½ miles east-south-east of Ernabella. Similar dykes have been noted cutting similar rock near Itjinpiri, 6 miles north of Ernabella.

No. 7967. A summary of the main mineralogical data is included in Table II.

In thin section the *plagioclase* appears as lathes which attain the size of 2 mm. x 0·05 mm., with many 1 mm. x 0·04 mm. (average probably about 0·4 mm. x 0·03 mm.). The lathes show no flow structure and are in some places criss-cross, in others intergrown with the "feathers" of pyroxene. The plagioclase (about 25% of the rock) is clear of the dusty inclusions so common in the dolerites of this area. The mineral is poorly twinned on Carlsbad and albite laws and measurements of extinction angles indicated a basic labradorite (An67-65%). Zoning is not common and *anorthoclase* rims are absent.

Pyroxene makes up about 55% (by volume) of the rock. It occurs in two forms. Up to two-thirds of the pyroxene form irregular and occasionally subhedral crystals up to 0·4 mm. x 0·3 mm. with an average size of 0·2 mm. x 0·2 mm. The mineral is a clear, non-pleochroic *augite* of fairly uniform composition as indicated by 2V varying only from 45° to 47° and $Z \wedge C = 37 \pm 2°$. The augite often shows an extinction similar to the "polarisation cross" noted in the pyroxenes of other dolerites of the area (*e.g.*, 7963).

The *other form of pyroxene* is that which helps to make the texture of this rock so distinctive. It occurs as feather-like and fan-like bundles of irregularly tapering rods. The bundles are on the average 0·6 mm. long x 0·2 mm. wide at the broad end and taper to 0·1 mm. wide at the apex, although some attain

the dimensions of 1 mm. x 0·4 mm. x 0·2 mm. The pyroxene individuals themselves are usually about 0·5 mm. long x 0·02 mm. wide. These plumose clusters show no preferred orientation, for sections cut perpendicular and parallel to the cooling surface show no significant difference (see pl. XVIII (b)).

The mineral may be of almost the same composition as the main augite, but no definite measurements could be made owing to the small size and the presence of a wavy extinction. However, its double refraction is similar to that of the augites, it has a medium extinction angle, is non-pleochroic and is often seen "sprouting" from the larger generation of clinopyroxenes. There is, however, small possibility that it is a "late pigeonite" similar to that found in No. 7968 and suspected in No. 7969.

Olivine (Fa 11%) is abundant (between 18 and 20%) and distinguished from the clear pyroxene by having (1) a faint fawn tint (and a very weak pleochroism; X slightly darker than Z), (2) many cracks filled with dusty iron ore and irregular patches of brownish dust, (3) a somewhat higher double refraction (2V (+ve) — 88°). The most striking feature of the mineral is its mode of crystallisation. Sometimes a solid subhedral crystal is seen, but usually it occurs as a strange type of zoned crystal. Orientated inclusions of a very fine mass of pyroxene and plagioclase (sometimes suggesting coarsely devitrified glass) are often so abundant and specially arranged that the crystal appears skeletal. Plate XVIII (a) shows a hexagonal form reminiscent of pseudo-hexagonal twinning (as is cordierite) but the arms of the crystal extinguish together and have no properties of twins. In some cases crystals of pyroxene well beyond the borders of an olivine are seen in optical continuity with pyroxene some distance within the skeletal olivine. Fairly large individuals of clinopyroxene have been enclosed by groups of olivine crystals in such a way as to suggest that some of the olivine crystallised after some of the clinopyroxene. In places olivine occurs as small granules and blunt ragged prisms intergrown with the plumose pyroxene.

The evidence indicates that though olivine began to crystallise first (as in all of these dolerites) it was soon followed by a clinopyroxene (but neither early pigeonite nor bronzite) which continued with the olivine for a relatively considerable length of time. While the last olivine was being formed the "plumose" generation of clino-pyroxene began its formation and continued to the end.

There is very little primary iron ore present, but most of the cracks in the olivine are filled with a dusty iron ore.

Neither early pigeonite nor bronzite is present, and no late pigeonite was proved. Anorthoclase was not noticed.

B. Dolerites (Olivine Free)

(1) Orthopyroxene-bearing Dolerites.

(a) *Orthopyroxene-bearing Dolerites with Ophitic Texture.*

1. *No.7970* is a small east-to-west dyke which intrudes gneisses near the junction with the charnockitic granodiorite about three miles west of Ernabella.

In hand specimen the rock is similar to the other dykes. In thin section the rock appears fairly fresh. A summary of the main mineralogical data is included in Table 11.

Most of the 57·6% of *plagioclase* in the rock is a basic labradorite (An66%) but cores are often as basic as a bytownite (An72%) and there is commonly a continuous gradation toward a narrow oligoclase border (about An35%). A little deuteric anorthoclase (2V (–ve) = 52°) is present, but no quartz was observed. The central part of many feldspar crystals shows the dusty inclusions so common in the dyke rocks of this area.

The *pyroxenes* present an interesting problem. It appears that both orthopyroxene and pigeonite have crystallised at much the same time. No evidence was found which was sufficient to prove which mineral began to crystallise first. The final pyroxenes to form are a mixture of subcalcic augite with some bronzite and pigeonite. The *orthopyroxene* is similar to that seen in No. 7961, and has a bronzite core (OF 16%) which gives way gradually in the more normal manner to a bronzite rim (about OF 22%). The bronzite shows marked lamellar twinning (|| (010)). The course of crystallisation in the clinopyroxenes, however, is difficult to follow. Some subhedral crystals are found showing a remarkable zoning. Occasionally the core is enclosing an enstatite (OF 9%) and is a *pigeonite* with $2V =$ about $20°$ and optic plane $\perp$ (010). Then follows a perfect gradation toward a uniaxial pigeonite ($2V = 0°$) into pigeonite with the optic plane || (010) ($2V = 0°$ to $30°$). Finally the gradation leads (with no hiatus) to a *subcalcic augite* with $2V = 40°$. The double refraction regularly increases slowly from the core to the rim, but the extinction angle ($Z \wedge C$) remains fairly constant (about $34°$). In such a zoned pyroxene abundant dusty iron ore inclusions have been precipitated when the 2V reached about $32°$ (fig. 3(d)). The remarkable feature of this zoning is the fact that bronzite, which shows a patchy extinction as well as a fine lamellar twinning (|| optic plane), is present in the same rock and may have crystallised at much the same time as the clinopyroxenes (see p. 197 for fuller discussion).

The pyroxenes comprise 34·7% (by volume) of the rock with the bronzite, pigeonite and subcalcic augite represented in probably equal proportions.

The texture of the rock is moderately ophitic, but a considerable number of the zoned clinopyroxenes have developed a subhedral form. The bronzite and some clinopyroxene have, in places, developed a notable bladed form and sometimes are seen in a coarse plumose form somewhat reminiscent of that in No. 7967.

(2) Normal Dolerites (*i.e.*, free from olivine and orthopyroxene).

These rocks are similar in many ways to the olivine-bearing suite described above. The absence of both olivine and orthopyroxene, however, and the presence of somewhat more ferriferous pyroxenes and more deuteric acidic material suggest that this group is probably a later differentiate from the common doleritic magma. Two types are recognised.

(a) *Normal Dolerites with Ophitic Texture.*

These are plentiful, especially in the eastern Musgrave Ranges. *No. 7971* is a coarse-grained dark grey dolerite which outcrops prominently about 4·4 miles from Kenmore Park on the track to Ernabella. It cuts the hypersthene granulites and gneisses at a steep angle. In thin section this coarse doleritic rock appears remarkably fresh, except for certain deuteric reactions. Mineralogical data are set out in Table 11.

The *plagioclase* (49·0%) is very well zoned with a composition showing perfect gradations from cores of labradorite (An66%) to rims of andesine (An34%). The probable average is a labradorite (An62%). The plagioclases show the characteristic pale brown dusty inclusions. The modal figure of 49·0% includes about 4% of clear acid deuteric material composed of both quartz and anorthoclase. The deuteric solutions have attacked the pyroxenes in places yielding a strongly pleochroic amphibole ($X =$ yellow-green, $Y =$ green, $Z =$ deep blue-green) with $Z \wedge C = 15°$, biotite ($X =$ yellow, $Y = Z =$ very dark brown) magnetite and apatite.

The amphibole comprises 5·8% of the rock, biotite 1·2% and about one-third of the 7% magnetite is a dull black secondary iron ore.

The *pyroxene* (37·0%) is a pinkish subcalcic augite somewhat more ferriferous toward the rim than at the core. The lowest optic axial angle observed was 2V (+ve) = 35° (and Z∧C = 38°), which was the outermost rim of a crystal with a core with 2V (+ve) = 40° (and Z∧C = 41°). Twinning on (010) is more plentiful in this pyroxene than in any other of this area. The double refraction is a little higher toward the rim but this is not as marked as in No. 7972. Neither pigeonite, bronzite, nor olivine is present.

(b) *Normal Dolerites with a Subophitic Texture.*

No. 7972 is a medium-grained dark grey dyke rock, and one of several which cut the gneisses forming the ridge between Gilpin's Well and the track linking Ernabella and Kenmore Park, and 20 miles from Ernabella.

In thin section the texture is somewhat different from that of the other dykes yet studied. Phenocrysts of clinopyroxene are present, as well as the smaller generation of smaller but more ferriferous pyroxene. It is in this later pyroxene that the subophitic texture is developed. The plagioclase, too, occurs in two poorly defined generations. The larger set are comparable in size with the phenocrysts of pyroxene. They show very marked discontinuous zoning (pl. XVIII (c)). The smaller set show the gradational zoning so common in this region. Mineralogical data are set out in Table II.

Plagioclase comprises 51·3% (this includes about 3% of deuteric quartz and anorthoclase). The average composition of the mineral is that of an acid bytownite (An72%) but the cores of some crystals are as basic as an anorthite (An91%), with the borders of many crystals reaching almost to an oligoclase (An31%). The plagioclase is stained a fawn-brown (contrast the 3% deuteric material which is clear).

The only pyroxene present is a subcalcic augite. The optical properties of the outer zones of the phenocrysts and smaller crystals suggest a gradual iron enrichment as the crystallisation proceeded (2V decreases from 39° to 36°; Z∧C increases from 40° to 42°; double refraction increases from core to rim).

Two or three very small corroded crystals of a faint dull brown olivine up to 0·3 mm. x 0·15 mm. occur as inclusions in the phenocysts of subcalcic augite. Beside the presence of quartz amongst the deuteric material, quartz occurs as an interesting xenolith. The clear mineral is surrounded by a prominent rim of subcalcic augite. The lens of quartz and pyroxene together is about 1·8 mm long x 1 mm. wide, with the actual core of quartz about 0·5 mm. x 0·3 mm. The plentiful iron ores (5·6%) comprise about half primary magnetite and the rest is dull black dusty secondary iron ore.

Neither "early" nor "late" pigeonite nor bronzite is present and only two or three tiny adventitious crystal of olivine occur.

V. PETROLOGY.[11]

In general the minerals of each dolerite indicate a normal course of crystallisation with a trend toward a soda enrichment in the plagioclase and an iron (and part calcium) enrichment in the pyroxenes (and olivines), phenomena ably discussed by several recent authors.

In several ways, however, the mineral assemblage differs considerably from that of dolerites described elsewhere, and associations obtain which have hitherto been largely thought improbable.

Some of the main unusual features will become apparent in a brief survey of the pigeonites of these rocks. (Table I). *Pigeonite* makes its appearance in

(11) Owing to lack of large sills no extended study of the course of crystallisation of the doleritic magma could be undertaken. The specimens here described were collected in the first instance to give an idea of the types of basic dyke rock in the area.

seven dolerites and in each with its own peculiar associations. On plotting the compositions of the ferromagnesian minerals of the pigeonite-bearing rocks in fig. 4, it is apparent that most of the augites and subcalcic augites fall below the "course of crystallisation" curve of Hess (1941, 585, fig. 10). When the pyroxenes reach a Fs content of between 35% and 40% further anomalies arise.

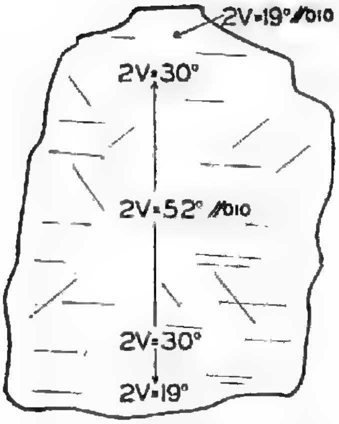
In three rocks (*7968*, *7965*, and *7961*) the "course" drops steeply and passes over the border ($2V = 30°$) into the pigeonite zone. These pigeonites have properties merging perfectly into the subcalcic augites. None of this type, however, has been found to gradually transgress the line ($2V = 0$) into the field of pigeonites with the optic axial plane ⊥ (010). Walker (1943, 518) has recorded similar cases and considers such pigeonites are "ferriferous and lie just below the ferro-augite field of the triangular diagram." He suggests that such pigeonites (optic axial plane ∥ (010) have 2V not much below 32°. In these rocks, however, 2V as low as 13° was measured (in 7965) and in 7970 all gradations exist from $2V = 20°$ (⊥ 010) through $2V = 0°$ to $2V = 40°$ (∥ (010)).

In *2450*, on the other hand, the course of crystallisation proceeds to Fs content of 40% and the subcalcic augite is joined by a pigeonite with $2V = 20°$ and optic axial plane ⊥ (010). The reason is unknown for such a marked break between the two clinopyroxenes in 2450, whereas a perfect gradation exists in Nos. 7961, 7965, and especially in *7968*. All are olivine dolerites and only No. 7961 contains any bronzite.

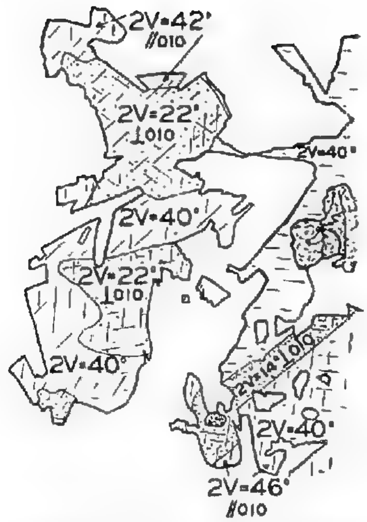
In *7965* there is an "early" as well as a "late" pigeonite (see above). The early pigeonite in this rock, however, is rare, and is always found enclosed by the augite ($2V = 46°$). Its optic axial plane is ⊥ (010), and there is consequently a sharp line of demarcation between the two pyroxenes. There is no bronzite in this rock, probably because the cooling was sufficiently rapid to prohibit the inversion of the early pigeonite. Olivine (Fa 21%) began to form early, continued throughout the cooling and is plentiful in the final crystallisation as small ophitic sphenoids (of much the same composition as the earlier material) and in association with the late pigeonite and some subcalcic augite.

In *2453* the crystallisation is interesting. Here (as in *7965*) a marked break is noted between the early pigeonite ($2V = 22° - 14°$; optic plane ⊥ (010)) and the other clinopyroxene. But the olivine (Fa 11%) is more magnesic, has already finished its main crystallisation and is found as rounded and partly corroded crystals in the pigeonites (and elsewhere). It does not appear as a later crystallisation. Moreover, the zoning of the clinopyroxene other than pigeonite is unusual. The early pigeonite gives way abruptly to a *subcalcic augite* ($2V = 40°$), which is gradually zoned till borders of *augite* are reached ($2V = 46°$). This suggests that this rock shows a course of crystallisation comparable (though farther from "Wo") with that to the left of the major "hump" of the curve of Hess.

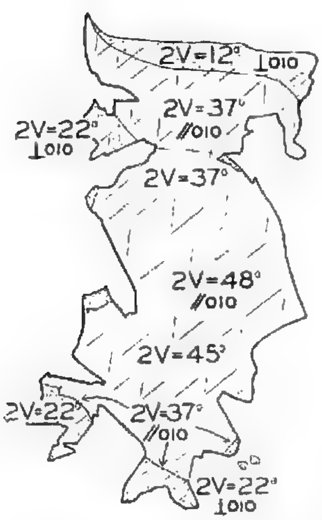
No. 7970 is a most interesting rock. Crystals of clinopyroxene occur showing a remarkable zoning. The core, which sometimes encloses and enstatite is a pigeonite ($2V =$ about $20°$; optic axial plane ⊥ (010)). Then follows a perfect gradation through uniaxial pigeonite ($2V = 0°$) into pigeonite ($2V = 0$-$30°$; optic axial plane ∥ (010), and finally into a subcalcic augite ($2V = 30°$-$40°$). Bronzite (OF 16-22%) is plentiful in the slide and in places is rimmed with subcalcic augites ($2V = 35$-$40°$). The bronzite shows a fine twinning (∥ optic axial plane (010)), and a shadowy extinction which suggests some exsolution of lime. It is difficult to explain the presence and apparent stability of the early pigeonite which has its optic axial plane ⊥ (010) and rims enstatite. Measure-



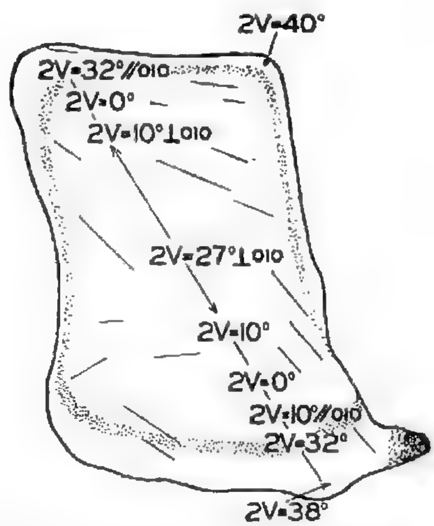
(a) *No. 7968.* Augite strongly zoned through subcalcic augite to rim of pigeonite (with optic plane ‖ (010)). (x 45).



(b) *No. 2453.* Early pigeonite with optic plane ⊥ (010)) enclosed by subcalcic augite (2V = 40°), which is itself zoned toward an augite rim (2V = 46°). The pigeonite is not as ophitic as the other clinopyroxene. (x 20).



(c) *No. 2450.* Augite (2V = 48°) zoned outward toward subcalcic augite (2V = 37°). A break occurs and pigeonite with optic plane orientated differently (i.e., ⊥ (010)) forms tips on the main crystal. (x 28).



(d) *No. 7970.* Pigeonite (with optic plane ⊥ (010) very strongly zoned toward uniaxial pigeonite, and thence into a pigeonite with a different orientation (*i.e.*, optic plane ‖ (010) and 2V = 30°. A gradation exists near the rim from this pigeonite into a subcalcic augite (2V = 40). Magnetite dust was precipitated while subcalcic augite (2V = 32) was crystallising. (x 35).

Fig. 3. Pigeonite Relations in Some Dolerites (see also fig. 4 and Table I)

ments of refractive index have indicated that this zoning shows a course of crystallisation fairly close to the diopside- clinoenstatite line and toward the extreme left of the two pyroxene field of Hess (1941, 586).

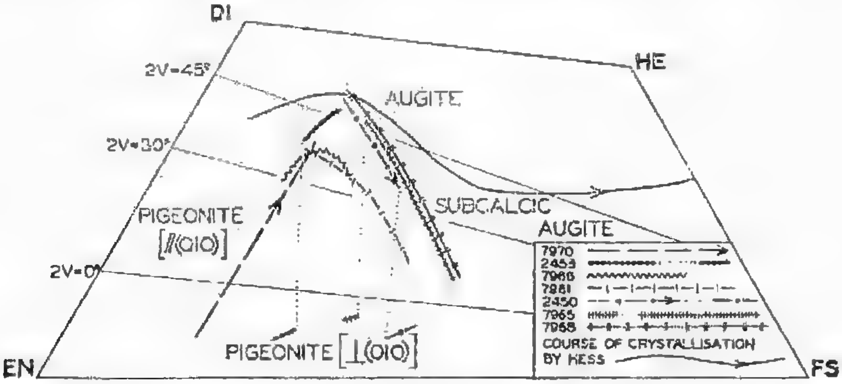


Fig. 4

Trends in crystallisation, as shown by the Clinopyroxenes of certain Pigeonite-bearing Dolerites, compared with the course of crystallisation suggested by Hess [Pyroxenes roughly plotted against γ-curves (Deer and Wager, 1938, p. 20, fig. 2) and approx. 2V curves (Poldervaart ,1947 (a), p. 161, fig. 2].

In the *non-pigeonite-bearing* dolerites (*e.g.*, 7963) a *bronzite* often occurs which shows a patchy extinction or *fine lamellar intergrowth,* apparently identical to that described elsewhere in orthopyroxenes within the range OF 15-35 (Poldervaart, 1947, 167, and pl. XIII, fig. 1). Hess seems to limit this phenomenon to orthopyroxenes with a composition about OF 30 or greater. In these dolerites the first appearance of this apparent inversion from early pigeonite seems to be in a bronzite with OF = 16 (as in 7970) and is found in all more ferriferous varieties to OF 22. In the coarse rock, No. 7964, much of the bronzite as magnesic as OF 12, shows a prominent patchy extinction.

Owing to the narrowness of the dykes the strange zoning phenomena shown by the clinopyroxenes cannot be explained by a gravitational settling of phenocrysts into deeper regions, especially in view of the fact that zoning is normal in both orthopyroxenes and plagioclases.

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2453	OLIVINE [Fa. 11] — PIGEONITE [2V = 14–22°; ⊥ (010)] - - - - - SUBCALCIC AUGITE [2V = 40 –45°] ——> AUGITE [2V = 46°]	No Bronzite
7965	OLIVINE [Fa. 21] - PIGEONITE [2V = 19°; ⊥ (010)] — AUGITE [2V = 48 –45°] ——> SUBCALCIC AUGITE [2V = 45 –31°] - - - - - - PIGEONITE - [2V = 30 –13°; ‖ (010)]	No Bronzite
2450	OLIVINE [Fa. 13] - - - - - - - - - - - - - - - - AUGITE [2V = 49—45°] ——> SUBCALCIC AUGITE [2V = 45 –37°] - - - - - - - — PIGEONITE - - - [2V = 22 –15°; ⊥ (010)]	No Bronzite
7968	OLIVINE [Fa.24] - - - - - - - - - - AUGITE [2V = 52 –45°] ——> SUBCALCIC AUGITE [2V = 45 –30°] - - - - - - - - - - - - [2V = 30 –19; ‖ (010)] - PIGEONITE -	No Bronzite
7966	OLIVINE [Fa. 19] - - - - - PIGEONITE [2V = 28; ‖ (010)] ——> SUBCALCIC AUGITE [2V = 38 –40 –35; ‖(010)]	No Bronzite
7961	OLIVINE [Fa. 12] - - - - - - - - - - - - - - - - - - BRONZITE [OF. 17—22] - - - - - - - - - - SUBCALCIC AUGITE [2V = 40 –30] - - - - - - - PIGEONITE - [2V = 30—25; ‖ (010)]	
7970	ENSTATITE [OF. 9—10] ——> - BRONZITE [OF. 16—22] - PIGEONITE [2V = 20 –0; ⊥ (010)] — ——> PIGEONITE [2V = 0] ——> PIGEONITE [2V = 0 –30; ‖ (010)] - - - - - SUBCALCIC AUGITE - [2V = 30 –40; ‖ (010)]	No Olivine

Table I. Order of Crystallisation of Ferromagnesian Minerals in certain Pigeonite-bearing Dolerites

ROCK NUMBER		7964	7963	2449	2460	7960	7961	7968	7966	2453	7965	2450	7967	7970	7971	7972
PLAGIOCLASE		33·9	34·3	54·2	43	64·1	61·4	42·5	58·1	59·7	55·4	55	28	57·6	45·0	51·3
PYROXENE		50·2	45·6	29·7	20	23·4	30·7	48·1	19·3	35·2	32·5	30	49	34·7	37·0	41·3
OLIVINE		8·0	16·1	11·8	15	5·7	1·9	6·6	6·3	2·2	8·0	12	20	—	—	—
ACCESSORIES		7·9	4·0	4·3	4	6·8	6·0	2·8	16·3	2·9	4·1	3	3	7·7	18·0	7·4
TEXTURE		POIKIL	SUB-OPH.	SUB-OPH.	SUB-OPH.	OPH.	OPH.	POIKIL.	SUB-OPH.	OPH.	OPH.	OPH.	"PLUMOSE"	OPH.	OPH.	SUB-OPH.
PLAG.	An. %	67—65	82—72—67	75—72—44	72	70—68—28	72—62—30	67	65—34	62	72—68—49	82—77—46	67—65	72—66—50	66—62—35	91—72—31
	Av. Diam.	4 × 1·5 m.m.	·9 × ·2	·8 × ·25	1 × ·4	·9 × ·2	1·4 × ·3	2 × 1	1·4 × ·6	1 × ·25	·9 × ·2	1·3 × ·4	·4 × ·03	1·4 × ·5	1·2 × ·4	·8 × ·4
AUGITES and SUBCALCIC AUGITES	2V	51—48	50—48—35	50—44—37	45—40	43—38—30	40—31	52—47—31	30—40—35	40—46	46—42—31	49—45—37	46	30—40	40—35	39—34
	Z∧C	37—36	42—39—38	38—39	39	40——36	37	36	39	38	41	38	37	32	41—38	40
	R. I.	1·695 = γ (2V = 48)	1·701 = γ (2V = 45)	1·692 = γ (2V = 44)	1·698 = γ (2V = 43)	1·708 = γ (2V = 38)	1·710 = γ (2V = 36)	1·705 = γ (2V = 47)	1·710 = γ (2V = 43)	1·680 = γ (2V = 43)	1·724 = γ (2V = 40)	1·695 = γ (2V = 45)	1·698 = γ (2V = 46)	1·705 = γ (2V = 35)	1·719 = γ (2V = 38)	1·724 = γ (2V = 36)
	Pleoch	Nil	Nil or cf. bronzite	Nil	Nil, to X = pink Z = faint green	cf. 7961	X = faint green Y = pinkish Z = yellow green	Nil or weak	X = faint rust pink Y = faint fawn Z = faint fawn grey	X = faint pink Y = Z = colourless	X = faint pink Y = Z = faint green	Nil	Nil	X = faint pink Y = Z = faint green	Nil to X = faint fawn Y = faint pink fawn Z = faint yellow fawn	X = faint pink Y = faint fawn Z = fawn grey
	Av. Diam.	1·4 × ·8 m.m.	·6 × ·3	·6 × ·5	·6 × ·4	·4 × ·4	·35 × ·25	·5 × ·4	·4 × ·3	2·5 × 1·5	1·6 × ·6 etc.	1·2 × 1	·2 × ·2, etc.	·3 × ·25, etc.	1·2 × ·8	·8 × ·6, etc.
PIGEONITES	2V	—	—	—	—	—	30—22	30—19	28—30	22—14	30—16; 19	22	—	28—0; 0—30	—	—
	Z∧C						37	30	39	39—38	29; —	38?		30		
	R. I.						1·715 = γ (2V = 25)	1·720 = γ (2V = 22)	1·720 = γ (2V = 29)	1·682 = γ (2V = 16)	1·730 = γ [2V = 22, ∥ (010)]	γ = 1·712 (2V = 22)		γ = 1·685 [2V = 15 ⊥ (010)] γ = 1·698 [2V = 25 ∥ (010)]		
	Pleochr.						cf. augite	X = Y = V. faint pink Z = colourless	cf. augite	X = Y = faint pink Z = faint green	cf. augite	Nil		cf. augite		
	Optic plane						∥ (010)	∥ (010)	∥ (010)	⊥ (010)	∥ (010); ⊥ (010)	⊥ (010)		⊥ (010; ∥ (010)		
	Av. Diam.						·2 × ·1	·3 × ·2	·3 × ·2	·6 × ·2	·3 × ·2	·4 × ·2		·4 × ·3		
ORTHO-PYROXENES	Comp.	OF. 8—OF. 16	OF. 22	OF. 22—OF. 26		OF. 18 — OF. 22	OF. 18 — OF. 22	—	—	—	—	—	—	OF. 9 — OF. 21	—	—
	2V	+83 to —81	—71	—72 to —66		—77 to —71	—77 to —71							+84 to —73		
	Pleoch.	Nil to X = rusty pink Z = faint green	X = pink Y = faint fawn Z = faint green	X = rusty pink Y = pale yellow Z = faint green	cf., 2449	cf. 7961	X = pink Y = faint green Z = pale green							X = pink Y = faint green Z = pale green		
	Av. Diam.	·4 × ·5 m.m.	·5 × ·3	1 × ·6	·4 × ·4	·6 × ·3	·8 × ·4									
OLIVINES	Comp.	Fa. 15	Fa. 18	Fa. 21	Fa. 12	Fa. 12	Fa. 12	Fa. 24	Fa. 19	Fa. 11	Fa. 21	Fa. 12	Fa. 11	—	—	—
	2V	—88	—87	—86	+89	+89	+89	—85	—87	+87	—86	+89	+88			
	Av. Diam.	1 × ·7 m.m.	·5 × ·3	·8 × ·6	·8 × ·5	·2 × ·3	·4 × ·3	·6 × ·4	·25 × ·2	·5 × ·4	·3 × ·25, etc.	·6 × ·4	·4 × ·3			
ANORTHOCLASE	%	5·2	Nil	2	2	2	4	Nil	4—5	0·4	Nil	0·2	Nil	2	3	2
	2V	—51 to —59		—42 to —52					—52					—52	—50	

TABLE 3

Chemical Analyses	1	2	3	4	5
SiO_2	47·98	48·61	49·35	47·80	49·27
TiO_2	0·90	0·82	0·63	1·23	2·13
Al_2O_3	13·79	13·35	13·15	14·30	13·57
Fe_2O_3	0·78	1·72	0·96	1·25	2·47
FeO	8·89	9·13	9·67	12·09	12·78
MnO	0·16	0·14	0·15	0·40	0·50
MgO	14·02	12·71	13·31	7·40	4·26
CaO	11·27	9·67	9·01	10·17	8·51
Na_2O	1·77	2·02	1·14	2·54	2·44
K_2O	0·39	0·44	1·13	0·60	1·42
H_2O+	0·31	1·06	0·94	1·87	0·55
H_2O-	0·02	0·22	0·09	0·44	0·22
P_2O_5	0·12	—	0·10	—	1·23
S	0·05	—	Nil	—	—
Cr_2O_3	0·19	0·24	Nil	—	—
Ba	Nil	—	Nil	—	—
Etc.	—	0·06	0·22	0·24	0·34
Totals	100·64	100·19	99·85	100·38	99·69

Norms		1	2	3	4	5
Q		—	—	—	—	2·64
OR		2·22	2·44	6·68	3·89	8·34
AB		15·20	16·97	9·65	21·48	20·44
AN		28·36	26·05	27·42	25·58	21·96
DI	WO	11·14	9·12	7·20	20·72	10·77
	EN	7·34	5·91	4·54		
	FS	2·98	2·59	2·21		
HY	EN	3·75	10·80	17·94	5·02	24·01
	FS	1·52	4·75	8·76		
OL	FO	16·81	10·54	7·47	17·05	—
	FA	7·53	5·10	4·06		
MT		1·16	2·55	1·39	1·86	3·71
IL		1·67	1·55	1·19	2·28	4·10
AP		0·34	—	0·24	—	2·69
PY		0·12	—	—	—	—
CR		0·22	0·33	—	—	—

S.G. = 3·13

C.I.P.W. = IV, 1, 2, 3.

Modes* (by Volume)	1	2
Feldspar	34·3	32
Late Feldspar	—	7
Pyroxene	45·6	42
Olivine	16·1	14
Accessories	4·0	5

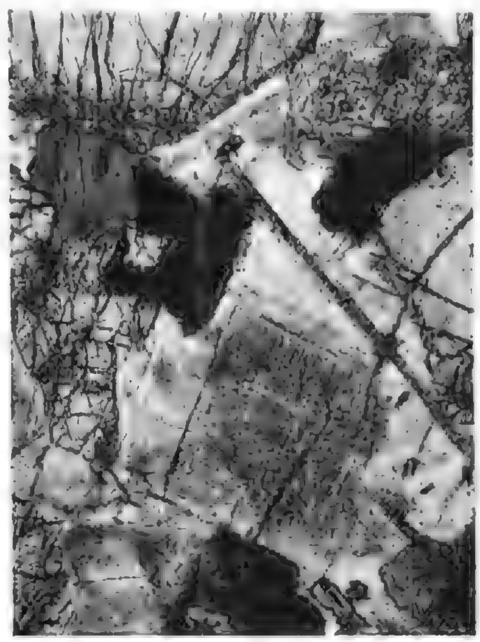
*Modes of 3, 4 and 5 not available.

1. Olivine Bronzite-bearing Dolerite, Rock Hole, 19 miles E. Ernabella, Musgrave Ranges, Anal., A. F. Wilson. No. 7963.
2. Olivine Dolerite, Kranskop, Orange Free State (Frankel, 1943).
3. Olivine Dolerite, Filabusi Dist., S. Rhodesia (Ferguson, 1934).
4. Dolerite, Norseman, W. Aus. Anal., E. S. Simpson (Campbell 1906, p. 119).
5. Quartz Dolerite, Mt. Holmes, W Aus., Anal., Survey Lab. (Farquaharson, 1912, p. 49).

(a) *No. 7967.* Olivine (Fa 11), showing marked skeletal and "hexagonal" form under crossed nicols. Inclusions mainly very fine pyroxene. x 60 (p. 194).

(b) *No. 7967.* "Plumose" pyroxene. This is abundant in the dolerite which contains the "skeletal" olivine. The acicular crystals may be seen "sprouting" from larger clinopyroxenes toward the base of the photo. Ordinary light. x 60.

(c) *No. 7972.* Plagioclase, strongly zoned from Anorthite (An 91) to Andesine (An 35). Subcalcic augite is other mineral. Crossed nicols. x 40.



(d) *No. 7964.* Clear anorthoclase (fig. 2) rimming labradorite (fresh but with abundant dusty inclusions). Biotite, rimming magnetite, occurs at bottom and top left. Long apatite needle included in anorthoclase. Pyroxene at top is euhedral augite; and that on right and left is enstatite rimmed with bronzite. Ordinary light. x 40.

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THE STRATIGRAPHY OF THE AITAPE SKULL AND ITS SIGNIFICANCE

By Paul S. Hossfeld

Summary

During April 1929, the writer was engaged on a geological survey of the northern slopes of the Barida Range near Aitape, Northern New Guinea. A survey of the lower section of the Paniri Creek, on 26 April, resulted in the discovery of several human skull fragments. On the completion, at the end of 1929, of the geological surveys in New Guinea by the Anglo-Persian Oil Company, to which the writer was attached as a geologist of the Australian Commonwealth Government, the skull fragments were taken to Australia, and later deposited in the Australian Institute of Anatomy at Canberra.

THE STRATIGRAPHY OF THE AITAPE SKULL AND ITS SIGNIFICANCE

By Paul S. Hossfeld *

[Read 9 September 1948]

INTRODUCTION

During April 1929, the writer was engaged on a geological survey of the northern slopes of the Barida Range near Aitape, Northern New Guinea. A survey of the lower section of the Paniri Creek, on 26 April, resulted in the discovery of several human skull fragments. On the completion, at the end of 1929, of the geological surveys in New Guinea by the Anglo-Persian Oil Company, to which the writer was attached as a geologist of the Australian Commonwealth Government, the skull fragments were taken to Australia, and later deposited in the Australian Institute of Anatomy at Canberra.

In a report by the Anglo-Persian Oil Company to the Commonwealth Government (Nason-Jones 1930) the discovery of the skull was referred to briefly and the associated rocks and fossils described. Nothing more was done until Fenner (1941) described the fragments and included a brief description of the site as supplied by the finder, the present writer. The present paper has been written in order to describe fully the stratigraphy of the location and its possible significance to human pre-history.

The writer holds the opinion that the occurrence of human remains in Pleistocene sediments in New Guinea, and the investigation of the relation of these deposits to the Pleistocene Ice Age, may supply important evidence of the advent of Man in Australia.

The region which will be described in some detail comprises that part of northern New Guinea which lies between the Dutch border on the west and the settlement of Aitape on the east, and extends inland from the coast to the foothills of the Bewani and Torricelli Mountains.

TOPOGRAPHY

Within this region there exist three well-marked hill areas. The most westerly extends into Dutch New Guinea and includes in its northern portion the Oenake-Bougainville Massif. The central area extends inland from the Serra Hills on the coast to the relatively low hills between the Bewani and Torricelli Mountains. The most easterly area consists of the northern foothills of the Torricelli Mountains and extends north towards Aitape, from which it is separated by a coastal strip of swampy lowland.

Between these hill areas the country consists of large areas of alluvium, containing a large proportion of sago swamps.

The junction of the hill areas and alluvium is sharply defined and is probably considerably less than 300 feet above sea-level. The hills rise steeply from the alluvium and attain heights of the order of 2,000 feet and over. The whole region with its juvenile drainage and sharp differentiation of hills and plains presents the appearance of an area from which the sea has receded recently. This view is supported by palaeontological and other evidence.

The western area of alluvium includes the floodplain of the Neumayer River and its tributaries, while the eastern area contains the floodplains of the Bliri, Pieni, Yalingi and Railu Rivers and smaller streams and their distributaries.

* Geology Department, University of Adelaide.

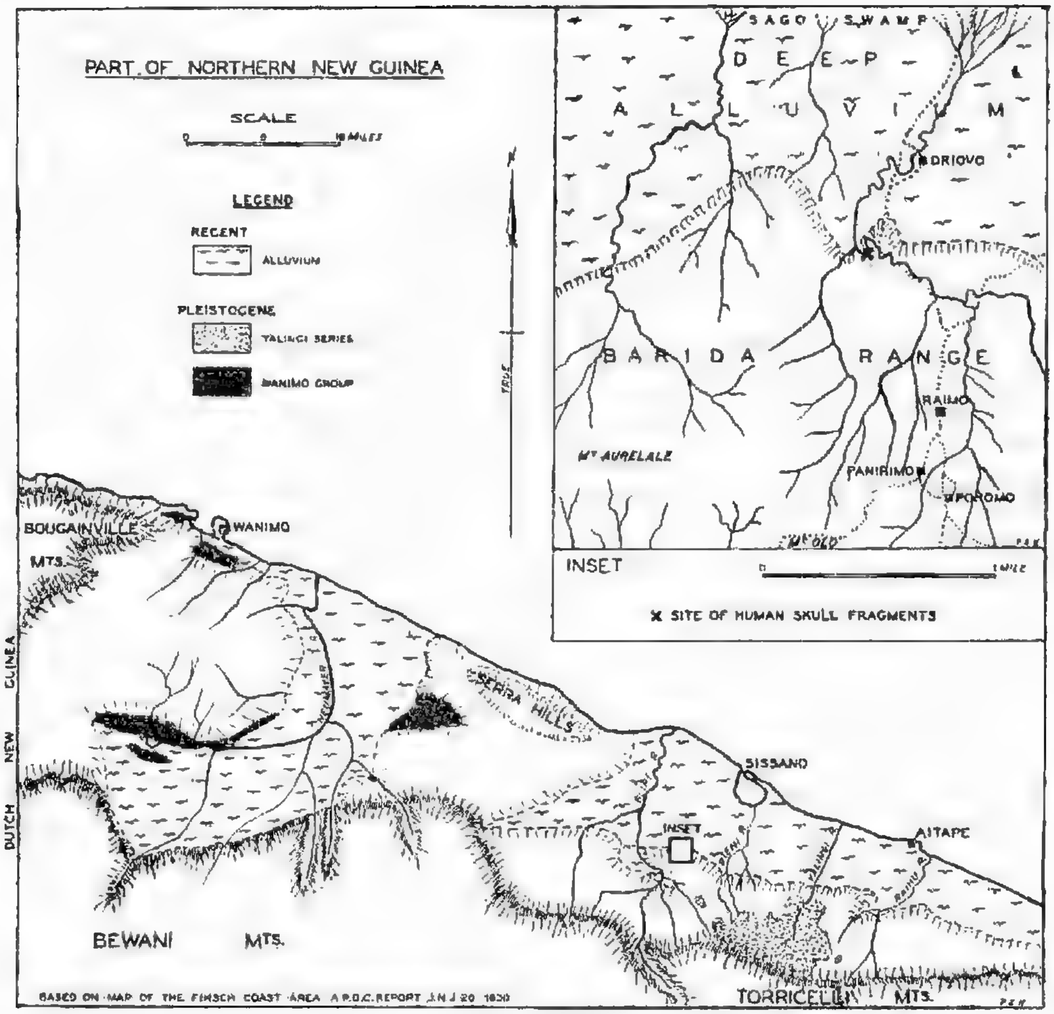

Fig. 1

GEOLOGY

The three hill areas consist of sediments belonging to the Lower Wanimo Group, Finsch Coast Series, the Upper and Lower Aitape Groups, and of the Oenake Series of igneous rocks. (Nason-Jones 1930.) The sediments range in age from Pliocene to Oligocene and possibly Late Eocene, while the igneous rocks are probably of pre-Tertiary age.

These Tertiary sediments exhibit steep folding and have developed complex structures. It is upon the eroded surfaces of these highly folded rocks that the gently dipping Pleistocene beds have been deposited.

The Pleistocene beds have been divided into two groups: (a) The Yalingi Series; (b) The Upper Wanimo Group.

(a) The Yalingi Series

These consist of beds of coarse pebbles and boulders, cemented in part, with some interbedded thin argillaceous and arenaceous bands. They form a sub-horizontal or gently dipping unconformable capping on the older rocks and are developed chiefly in the Upper Nengo-Yalingi River area. Although subsequent

dissection has broken the former continuity of this "sheet" in many places, its former extent as a fluviatile outwash deposit on a gently sloping relatively even surface can be recognised (Nason-Jones 1930).

(b) The Upper Wanimo Group

This consists of a calcareous and an argillaceous facies. In general, the beds of this group outcrop along the intersection of the hill areas and the coastal alluvial plains, and their inland continuations at elevations above sea-level estimated in most instances not to exceed 200 feet. The few isolated high level occurrences observed present anomalous features suggesting fault movements and local elevation.

The general picture is that of relatively thin deposits fringing an old coast line which is marked by the lower slopes of the hill areas described above. The beds dip gently up to five or six degrees away from these areas and disappear under the alluvium of the plains. The soil cover and luxuriant vegetation limit the outcrops of these beds to the banks of streams. In these, the beds occur only near the junction of the hill areas and the plains. These beds exhibit no evidence of folding, the only earth movements in which they appear to have participated being those due to faulting, which are local in character wherever observed.

As a rule, the calcareous facies is developed wherever the rocks of the hill area consist of calcareous or igneous material, and the argillaceous facies wherever the blue mudstones (bentonitic in part) of the Lower Wanimo and Finsch Coast Series supplied the detrital material.

The argillaceous facies in which the human remains were discovered consists of blue mudstones and siltstones interbedded with some more arenaceous beds and containing a few richly fossiliferous horizons.

Current bedding was noted but is not a general feature. The beds are characterised throughout by the occurrence of broad zones containing partly carbonized driftwood and other hard plant remains distributed irregularly through the zones. The abundance of this driftwood, the presence of current bedding and lenticular beds, and the recognition of fossil shells of fresh and brackish water and marine forms indicates the close proximity of a former shore line to a shallow sea, or alternatively, deltaic conditions. The origin of these beds as deltaic sediments, except in restricted areas, is discounted by their apparent continuity as deposits fringing the former coastline.

The opinion that these beds originated under shallow water conditions in quiet backwaters in which estuarine and marine deposits were intermingled, and the author's long association with anthropology, led to the close examination of the beds for human and animal remains, when and where this did not detract materially from the primary objective of the Survey, the geographical and geological mapping of the area for its petroleum potentialities. All such examinations of these Pleistocene deposits had therefore to be brief, and the author considers himself fortunate that despite the incompleteness of the examination, which should have occupied months instead of the few hours that could be devoted to it, the search was rewarded by the discovery of the human skull fragments.

The examination of a section of these beds exposed in a cliff face forming the bank of the Paniri Creek just above its junction with the Kiyen Creek, showed a completely undisturbed layer of fossil shells dipping gently in a northerly direction. The close examination of as much material as was possible in the time available—about four hours—resulted in the discovery of the skull fragments and a carbonized fossil fruit resembling a coconut, and the collection of a number of shells and material containing foraminiferal remains. The skull fragments were obtained at a level approximately four feet below the eroded upper surface of the formation, of which a total thickness of 10 feet is exposed in this section.

The eroded upper surface of this formation is overlain by coarse gravel beds, twelve feet in thickness, which immediately underlie the subsoil, soil and primary forest cover.(1)

SECTION OF BANK OF LOWER PANIRI CREEK

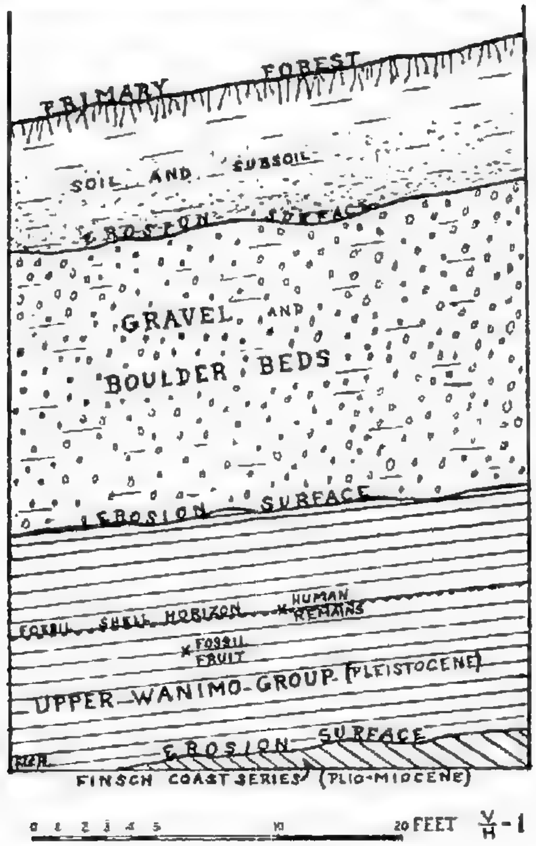

Fig. 2

The whole of this sequence is exposed in the cliff face forming the site of the discovery and is reproduced in the section included in the text.

While a search of the site failed to disclose any other remains either human or animal, this search was by no means exhaustive. Further, the occurrence of outcrops of this formation in numerous places, which could be given only a brief examination, as well as their recorded occurrence outside the areas surveyed by the author, suggest the necessity for their detailed examination for human and animal remains, an examination that was not within the scope of the petroleum survey during which the discovery was made.

The skull fragments have been described in detail by Fenner (1941), and the associated fossils by the Commonwealth Palaeontologist, see Nason-Jones (1930), and by B. C. Cotton, see Fenner (1941). While there is some discrepancy in the two lists of species identified, due partly perhaps to the fact that two separate lots were examined, both writers agree that the fossil suite exhibits forms of fresh and brackish water and marine species.

The collection of fossils submitted to the Commonwealth Palaeontologist, whose identifications are quoted below (Nason-Jones 1930), included, it was

(1) Through an error, for which the present writer is responsible, the information supplied to Fenner gave the thickness of the gravel beds as 6 ft.

believed, all the types represented, and was the main collection. The collection retained by the present writer and examined later by Cotton (Fenner 1941) contained, it was thought, only such types as were duplicated.

The following fossils, obtained from this site by the present writer, are listed by Nason-Jones (1930):—

PELECYPODA—	
Arca nodosa	*Paphia* aff. *alba*
cf. *Erycina* sp.	*Placenta mandiranljonensis*
GASTEROPEDA—	
Neritina sp.	*Melania denisoniensis*
Melania woodwardi	*Melania scabra*
FORAMINIFERA—	
Cibicides praecinctus	*Heterostegina* sp.
Cristellaria orbicularis	*Operculinella venosa*
Cristellaria cultrata	*Operculina granulosa*
Cristellaria calcarata	*Polystomella craticulata*
Eponides tumidus	*Quinqueloculina lamarckiana*
Eponides procera	*Rotalia* sp. nov.
Epistomina elegans	*Rotalia schroeteriana*
Globigerina triloba	*Rotalia papillosa*

Cotton (Fenner 1941) lists the following fossils in the lot examined by him which too was collected at the site by the present writer:—

Arca (Tegillarca) granosa Linn.	*Cyclophorus* sp.
Telescopium fuscum Schumacher	*Melania* cf. *juncea* Lea
Papuina sp.; Land Shell	*Melania* cf. *recta* Lea
Neritina cornea Linn.	*Melania* cf. *canaliculata* Reeve
Neritina souverbiana Montrouzier	*Cyrena coaxans* Gmelin
Laoma sp.	

The fossil fruit was submitted to Professor T. G. B. Osborn, at that time Professor of Botany at the University of Sydney. A report on the examination was forwarded to the writer and the following is a summary of Professor Osborn's conclusions.

"Morphologically this palm fruit closely resembles that of *Cocos nucifera*, the coconut. Its drupaceous unilocular character places it close to Cocos in the Cocoineae section of the Palmaceae. Its large size is also characteristic of the fruit of the coconut palm. Anatomically it also shows a strong resemblance to *Cocos nucifera*."

As stated above, the argillaceous deposits included in the Upper Wanimo Group occur on the lower slopes of the hill areas near their intersection with the alluvial plains, and lie unconformably upon the eroded surfaces of the steeply folded rocks ranging from Pliocene to the older Tertiary in age. In the Barida Range area they were observed in all the streams draining that range, both on the northern and seaward slopes as well as on the southern slopes facing the Mene-Bliri River floodplain, and parallel to the valley sides of those two streams.

They were recognised also on the southern and inland slopes of the Oenake Range facing the Pual-Neumayer Plain, and to a less extent on the northern and seaward slopes of that range.

DISCUSSION

A review of the literature dealing with the island of New Guinea indicates that argillaceous and calcareous deposits referable to this formation have been observed in many localities presenting similar topographic features. These

Pleistocene deposits will be referred to in detail in a paper which is in course of preparation. Various observers are in agreement that these deposits and the enormous areas of juvenile drainage characteristic of the island of New Guinea indicate recent emergence of the land and hence elevation. It is true that numerous localities are known where differential movement has taken place. However, the occurrence at intervals around the island of coastal plains with their abrupt transition to hill areas, and the wide distribution of shallow water deposits of muds and silt fringing the hill areas, would necessitate, if elevation of the land be postulated, the upward movement of the whole of the island of New Guinea as a block.

The writer is unable to accept this hypothesis and believes that alternations in sea-level supply the correct explanation for the regional character of these topographic and stratigraphic features.

Alternations in sea-level have been due to various causes. In discussing marine sediments and features of Pleistocene age, however, the effects of the generally accepted fluctuations in sea-level during the Pleistocene Ice Age merit first consideration. In the writer's opinion such fluctuations can and do explain satisfactorily the topographic and stratigraphic features discussed above.

It is suggested as probable that the upper limit of transgression of the beds of the Upper Wanimo Group, where the heights above sea-level of such limits are consistent over a sufficiently large area, marks the upper limit of transgression of the Pleistocene Ocean prior to the commencement of the First Glacial Period.

If this is accepted, the first retreat marks the commencement of the Pleistocene Ice Age. In the locality discussed in detail, fluctuations and subsequent advances and retreats of the sea are masked by the extensive alluvial deposits. However, the observed erosion surface on the upper surface of the argillaceous facies of the Upper Wanimo Group and deposition thereon of water-sorted gravels suggest the return of the sea to its original limits, and such return could perhaps be correlated with the First Interglacial Period.

It might be argued that the postulated successive advances and recessions of sea-level during the Pleistocene Ice Age could account for the varied environment of the fossil fauna of the Paniri Creek deposit. The deposit, however, exhibits no evidence of any break in deposition from its base where it rests unconformably on the Finsch Coast Series, to its upper eroded surface on which lie the gravel and boulder beds. Further, although the fossil shells and foraminifera exhibit a varied environment, all of them were obtained from the narrow zone indicated in the accompanying section. It is obvious, therefore, that if successive advances of the sea occurred, sea-level rose to its original height only once, at the stage during which the upper parts of the deposit were eroded, or alternatively, if a number of advances of the sea occurred, all evidence of previous transgressions except that of the last two has been removed completely. If such were the case, then the deposits in question could have been laid down at a late stage of the Pleistocene. Further research may permit of a decision being made, but if the latter supposition should prove to be correct, then the writer's view that these deposits date back to Early Pleistocene obviously cannot be maintained.

The writer desires to point out, however, that should it be possible to correlate the initial retreat of the sea due to the commencement of the Pleistocene Ice Age with the upper limits of the Wanimo Group, the occurrence of human remains with Australoid affinities in these beds would prove the existence of Man in New Guinea prior to the commencement of the Ice Age. It would follow that Man, even if he had no knowledge of sea travel, could have entered Australia as soon as the increase in the amount of glaciation had lowered sea-level sufficiently for him to cross the present Torres Strait over narrow and shallow

stretches of water. Even should further research place these beds higher in the Pleistocene sequence than postulated by the writer, their dating, if this be found possible, will have an important bearing on the date of the entry into Australia of Australoid Man.

The emphasis placed on the argillaceous facies rather than on the calcareous facies of the Upper Wanimo Group is due to the greater amount of information supplied by the former and the difficulty in many instances of determining by field examination the age of the calcareous deposits.

A study of both facies will be necessary if further work in the directions indicated is undertaken.

The widespread occurrences of the argillaceous beds, however, and the possible occurrence in them of animal and human remains, suggests the importance of a detailed examination of all the accessible deposits of this formation not only in New Guinea, but also the search for them in adjacent islands.

SUMMARY

This paper describes in detail the occurrence inland from Aitape, in Northern New Guinea, of fossil human skull fragments embedded in and contemporaneous with deposits of Pleistocene Age. In the writer's opinion, it may be possible to correlate the upper beds of these deposits with the commencement of the Pleistocene Ice Age and to date them therefore as Early Pleistocene, but much more research is necessary before such a correlation can be accepted. It is pointed out also that the widespread occurrence of such deposits in New Guinea (and probably in adjacent islands) offers a promising field for such research. Any positive evidence which would assist the dating of these deposits would affect materially the views held of the time of Australoid Man's entry to Australia.

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ON SOME REPTILES AND AMPHIBIANS FROM THE NORTHERN TERRITORY

BY ARTHUR LOVERIDGE

Summary

In herpetological literature of a century ago Port Darwin and Port Essington frequently appeared as type localities of considerable importance. Since those days relatively little has been added to our knowledge of the herpetofauna of Australia's Northern Territory. It was, therefore, with considerable satisfaction that the Museum of Comparative Zoology at Harvard University received part of the collections made during 1944 and 1945 by Mr. T. R. Tovell of the Australian Imperial Force, particularly so as it contained half-a-dozen species unrepresented in the museum's collection, of which one – Typhlops tovelli – had to be described as new.

ON SOME REPTILES AND AMPHIBIANS FROM THE NORTHERN TERRITORY

By Arthur Loveridge [1]

(Communicated by H. Womersley)

In herpetological literature of a century ago Port Darwin and Port Essington frequently appeared as type localities of considerable importance. Since those days relatively little has been added to our knowledge of the herpetofauna of Australia's Northern Territory. It was, therefore, with considerable satisfaction that the Museum of Comparative Zoology at Harvard University received part of the collections made during 1944 and 1945 by Mr. T. R. Tovell of the Australian Imperial Force, particularly so as it contained half-a-dozen species unrepresented in the museum's collection, of which one—*Typhlops tovelli*—had to be described as new.

Unfortunately, the data accompanying the first consignment was not too precise. Subsequently, Mr. Tovell kindly supplied me with the following information about the localities which had originally been summarised as "near Darwin".

They are Batchelor, at about 60 miles south of Darwin; Berrima and Knuckey's Lagoon, about 9 miles; Koonowarra, about 7 miles; and Noonamah, about 24 miles south of Darwin.

Typhlops tovelli (Loveridge)

Typhlops tovelli Loveridge, 1945, Proc. Biol. Soc. Washington, 58, 111: Koonowarra Sports Ground, Northern Territory, Australia.

2 (M.C.Z. 48844-5), Koonowarra Sports Ground.

Midbody scale rows 20; snout rounded, nasal cleft proceeding from preocular. Diameters included in total length 36-40 times. Total length, 122 (118·5 + 3·5) mm.

Typhlops guentheri Peters

Typhlops (*Onychocephalus*) *guentheri* Peters, 1865, Monatsb. Akad. Wiss. Berlin, 259, pl. ——, fig. 1: Northern Australia.

1 (M.C.Z. 48843), Batchelor.

Midbody scale-rows 18; snout rounded; nasal cleft proceeding from second labial. Diameter 2·75 mm., included in total length 63 times. Total length 175 (172·5 + 2·5) mm.

This blind snake appears to be closely related to *T. wiedii* Peters of Brisbane, Queensland. It would be interesting to know whether this black-tailed species carries the tail upraised like a false head, after the manner of the Asiatic *Maticora*, the African *Chilorhinophis*, the American *Apostolepis*, etc.

Natrix mairii mairii (Gray)

Tropidonotus mairii Gray, 1841, in Grey, Journ. Exped. West Australia, 2, 442: Australia.

11 hatchings (M.C.Z. 48851-61), Winnellie near Darwin.

Midbody scale-rows 15; ventrals 136-146; anals 2; subcaudals 56-61; upper labials 8, the third, fourth and fifth entering the orbit, except on right side of M.C.Z. 48858 where third and fourth are fused resulting in 7 labials; lower labials 8, the first five in contact with the anterior chin shield; preoculars 1,

[1] Museum of Comparative Zoology, Cambridge, Mass., U.S.A.

except on left side of M.C.Z. 48859 where there are 2; postoculars 3. Total length about 187 (147 + 40) mm.

These eleven young were taken from a batch of twelve eggs, one of which had already hatched, found about 20 April, i.e., at the beginning of the dry season, beneath a pile of rubbish. When found some eggs were single, others slightly cemented together in twos or threes. They measured approximately 25 x 16 mm (T. R. T.).

Trinomials are necessary since the separation by Brongersma (1948) of a well-defined race in Dutch New Guinea.

CERBERUS RYNCHOPS AUSTRALIS (Gray)

Homalopsis australis Gray, 1842. Zool. Misc., 65: Port Essington, Northern Territory, Australia.

♀ ♀ (M.C.Z.) 48846, 48862), Fanny Bay about $1\frac{1}{2}$ miles from Darwin.

Midbody scale-rows 23-25; ventrals 143-144; anals 2; subcaudals 49-51; nostril cleft in contact with second labial; upper labials 8-10; separated from orbit by suboculars; 3-4 lower labials in contact with an anterior chin shield. Larger ♀ (M.C.Z. 48862), 587 (486 + 101) mm.

One was found lying at the bottom of a salt pan (T. R. T.). That *Cerberus*, and not *Hurria*, is the correct name for these water snakes was pointed out by Malcolm Smith (1930), and that *rynchops*, not *rhynchops*, was Schneider's original spelling by Loveridge (1948) when describing a new race and providing a key to the genus.

ASPIDOMORPHUS CHRISTIEANUS (Fry)

Pseudelaps christieanus Fry, 1915, Proc. Roy. Soc. Queensland, 27, 91, fig. 6: Port Darwin, Northern Territory, Australia.

♀ (M.C.Z. 48847), near Darwin.

Midbody scale-rows 17; ventrals 195; anals 2; subcaudals 47; labials 7, third and fourth entering the orbit. Total length 350 (300 + 50) mm.

This gravid ♀, which carries three eggs each measuring about 26 x 6 mm., has more ventrals and fewer subcaudals than the topotype ♂ already in our collection. That *Pseudelaps* of Duméril is a synonym of *Aspidomorphus* has been shown by Brongersma (1934, Zool. Med. Mus. Leiden, 17, 224).

DEMANSIA PSAMMOPHIS (Schlegel)

Elaps psammophis Schlegel, 1837, Phys. Serp., 2, 455: Australia. *Elapocephalus ornaticeps* Macleay, 1878, Proc. Linn. Soc. N.S.W., 2, 221: Port Darwin, Northern Territory, Australia.

♂ ♀ (M.C.Z. 48848-9), Batchelor and Berrima.

Midbody scale-rows 15; ventrals 180-181; anals 2; subcaudals 70 (♀) –91 (♂) pairs; upper labials 6, the third and fourth entering the orbit. Total length of ♂ (M.C.Z. 48848), 290 (232 + 58) mm.

The head of the young ♀ is black above and scarcely distinct from the deep black nuchal bar; the body is fawn, each scale with a somewhat paler edge. The head of the older ♂ is olive with the markings described by Macleay.

I follow Kinghorn (1942, 118), who has had the advantage of examining much more material, in relegating *ornaticeps*, of which these specimens are almost topotypes, to the synonymy. However, the name proposed by Macleay was *Elapocephalus*, not *Elapognathus* as cited by Kinghorn. Kinghorn's conclusion appears to have been based largely on the highly variable colouration, known to change with age. I would suggest the possibility of a northern race with more numerous subcaudals for which the name *olivacea* Gray, 1842, would be available. If the Australian Museum's material could be sexed and arranged geographically to supplement that furnished by Boulenger (1896, 322-324), while ignoring Boulenger's arrangement based on colour, the point might be settled.

Demansia textilis nuchalis (Günther)

Pseudonaja nuchalis Günther, 1858, Cat. Snakes Brit. Mus., 3, 227: Port Essington, Northern Territory, Australia.

♂ (M.C.Z. 48850), near Noonamah.

Midbody scale-rows 17; ventrals 197; anals 2; subcaudals 63+ pairs; upper labials 6-7 (left and right), the third and fourth entering the orbit. Total length of ♂, 1130+ (940 + 190+) mm.

Heteronota binoei Gray

Heteronota binoei Gray, 1845, Cat. Liz. Brit. Mus., 174; Houtman's Abrolhos, Western Australia.

18 (M.C.Z. 48801-6), Batchelor or Berrima.

Dorsal tubercles keeled, in 12-16 rows, usually 14; preanal pores of eight males 4-5. Largest ♂ (M.C.Z. 48801), 105 (48 + 57) mm.

By day these geckos hide under any object not of tin or iron, the heat of which is too great during the noon hours (T. R. T.).

Diplodactylus spinigerus ciliaris Boulenger

Diplodactylus ciliaris Boulenger, 1885, Cat. Liz. Brit. Mus., 1, 98, pl. viii, fig. 2: Port Darwin, Northern Territory, Australia.

Juv. (M.C.Z. 48807), near Darwin.

Dorsal tubercles flat, forming 2 ill-defined rows; no pores. Length, 53 (32 + 21) mm.

Oedura rhombifer Gray

Oedura rhombifer Gray, 1844, Zool. Erebus & Terror, Rept., pl. xvi, fig. 6: Australia.

♂ (M.C.Z.), near Darwin.

Dorsals granular, small; femoral pores 12 + 12, being separated in preanal region by five scales; tail depressed, oval. Length 87 (43 + 44) mm.

The shape of the tail conflicts with Boulenger's redescription and conforms to what has been noted by Kinghorn (1942, 120).

Since the separation of the African geckos under the name of *Afroedura* (Loveridge, 1944), the range of *Oedura* is restricted to the Australian region.

Gehyra variegata australis Gray

Gehyra australis Gray, 1845, Cat. Liz. Brit. Mus., 163: Port Essington and Swan River, Australia.

♂ ♀ (M.C.Z. 48864-5), near Darwin.

Dorsals granular, small; preanal pores 14 in male; scansors not separated by a median groove. Length of ♂, 124 (62 + 62) mm.; ♀, 109 (53 + 56) mm.

Taken in an old building at McMillan's (T. R. T.). *Gehyra* (part) Gray, 1834, antedates the use of *Peropus* Wiegmann, 1835, for this genus.

Diporiphora bilineata Gray

Diporiphora bilineata Gray, 1842, Zool. Misc., 54: Port Essington, Northern Territory, Australia.

5 (M.C.Z. 48808-11), Batchelor or Berrima.

Gular fold absent; preanal pores 2 in male; tail twice the length of head and body. Length of ♂ (M.C.Z. 48808), 179 (52 + 127) mm.; ♀ (M.C.Z. 48809), 166 (55 + 111) mm.

Tiliqua scincoides scincoides (Shaw)

Lacerta scincoides Shaw, 1790, in White, Journ. Voyage N.S.W., App., 242, pl. ———: New South Wales.

Juv. (M.C.Z. 48817), Berrima.

Midbody scale-rows 36; anterior temporal as long as interparietal; forelimb shorter than head and contained about twice in distance from axilla to groin. Length, 154 (102 + 52) mm.

In view of its small size the proportions of this skink are interesting for comparison with those of the New Guinea race—*T. s. gigas* (Schneider).

LYGOSOMA (SPHENOMORPHUS) TAENIOLATUM TAENIOLATUM (Shaw)

Lacerta taeniolata Shaw, 1790, in White, Journ. Voyage N.S.W., App., 245, pl. xxxii, fig. 1: New South Wales.

3 (M.C.Z. 48818-20), Batchelor or Berrima.

Midbody scale-rows 24-26; prefrontals separated. All three are immature.

Owing to the findings of Malcolm Smith (1937, 213), *Sphenomorphus* and *Leiolopisma* are relegated with some misgivings to their former status of subgenera or, as Smith prefers to call them, "sections".

LYGOSOMA (SPHENOMORPHUS) FISCHERI Boulenger

Lygosoma fischeri Boulenger, 1887, Cat. Liz. Brit. Mus., 3, 228; n.n. for *L. muelleri* Fischer (preoc.), 1882, Arch. Naturg., 295, pl. xvi, fig. 16-19: Nicol Bay, Western Australia.

2 (M.C.Z. 48821-2), Batchelor or Berrima.

Midbody scale-rows 30; prefrontals separated; colouring characteristic Length of ♀, 143 (49 + 94) mm.

Encysted nematodes are numerous on external surface of stomach.

LYGOSOMA (SPHENOMORPHUS) ISOLEPIS ISOLEPIS Boulenger

Lygosoma isolepis Boulenger, 1887, Cat. Liz. Brit. Mus., 3, 234, pl. xv, fig. 1: Nicol Bay and Swan River, Western Australia.

♀ (M.C.Z. 48823), Batchelor or Berrima.

Midbody scale-rows 30; lamellae beneath fourth toe 23. Length of ♀, 149 (72 + 77) mm., but tail-tip regenerated.

Agreeing in all respects with the typical form rather than with *L. i. forresti* Kinghorn (1932, 358), this gravid ♀ holds four eggs measuring about 12 x 7 mm.

LYGOSOMA (LEIOLOPISMA) PECTORALE (De Vis)

Heteropus pectoralis De Vis, 1885, Proc. Roy. Soc. Qld., **1**, 169: Warro, Port Curtis, Queensland.

14 (M.C.Z. 48826-36), Batchelor or Berrima.

Midbody scale-rows 26-32; lamellae beneath fourth toe 19-27, in one specimen there are 24 on the right and 27 on the left toe. Largest ♂ (M.C.Z. 48826), 118 (41 + 77) mm.

In addition there were 13 damaged examples from same series or "near Darwin", which were not retained. All but two of them were of the strongly keeled *pectorale* type, two others with dark throats represent the synonym *mundum* De Vis (1885), their dorsal scales being almost smooth yet faintly tricarinate dorso-laterally.

A large specimen was recovered from the stomach of a *Lialis burtonis*. In the axilla of another of these skinks were some mites (*Trombicula* sp. n.), for whose identification I am indebted to Mr. H. Womersley of the South Australian Museum. The species will be described in Mr. Womersley's forthcoming monograph.

LYGOSOMA (LYGOSOMA) PUNCTULATUM Peters

Lygosoma punctulatum Peters, 1871, Monatsb. Akad. Wiss. Berlin, 646, pl. ———, fig. 5; Port Bowen, Queensland.

1 (M.C.Z. 48866), Winnellie, near Darwin.

Midbody scale-rows 20; digits 5; toes 5; lamellae beneath fourth toe 14. Length 118 (44 + 74) mm.

In life brown with a coppery sheen (T. R. T.).

LYGOSOMA (LYGOSOMA) PUMILIUM Boulenger

Lygosoma pumilium Boulenger, 1887, Cat. Liz. Brit. Mus., 3, 325: Cape York, Queensland.

2 (M.C.Z. 48834-5), Batchelor or Berrima.

Midbody scale-rows 20; digits 5; toes 5; lamellae beneath fourth toe 18-19. Larger measures 91 (41 + 50) mm.

The alleged difference in relative size of nostril and ear-opening between *pumilium* and *punctulatum* is not apparent. *L. pumilium* seems to be closely related to *crassicaudum* which Malcolm Smith (1937, 322) refers to his new section *Ictiscincus*.

ABLEPHARUS BOUTONII METALLICUS Boulenger

Ablepharus boutonii var. *metallicus* Boulenger, 1887, Cat. Liz. Brit. Mus., 3, 347: North Australia.

4 (M.C.Z. 48337, 48867), Batchelor or Berrima.

Midbody scale-rows 22-24; lamellae beneath fourth toe 17-20. Largest only measures 93 (38 + 55) mm.

In life iridescent grey with black markings. Found on trees and posts, not under logs or in grass. A very active skink (T. R. T.).

ABLEPHARUS LINEOOCELLATUS LINEOOCELLATUS Duméril and Bibron

Ablepharus lineo-ocellatus Duméril and Bibron, 1839, Erpét. Gén., 5, 817: Australia.

5 (M.C.Z. 48838-42), Batchelor or Berrima.

Midbody scale-rows 24-26; lamellae beneath fourth toe 17-18; supranasals absent. All young, the smallest only 29+ (14+ 15+) mm., its tail-tip missing. This little snake-eyed skink disgorged a spider.

DELMA FRASERI FRASERI Gray

Delma fraseri Gray, 1831, Zool. Misc., 14: Western Australia.

4 (M.C.Z. 48812-5), Batchelor or Berrima.

Snout as long as, or longer than, the distance between eye and ear; frontonasals in 2 pairs; fourth labial below eye; midbody scale-rows 16; anals 3, except in M.C.Z. 48814, where the wedge-shaped central scale fails to reach the anal border. Largest measures 75 mm. from snout to anus, tail missing.

All taken beneath rocks; quite common in this area (T. R. T.).

LIALIS BURTONIS Gray

Lialis burtonis Gray, 1834, Proc. Zool. Soc. London, 134: New South Wales.

♀ (M.C.Z. 48816), Berrima.

Rostral twice as broad as high; upper labials 14; preanal pores 4; colour form *punctulata*. Length of ♀, 260 (200 + 60) mm., but tail regenerating.

The oviducts of this gravid ♀ held two undeveloped eggs measuring about 20 x 12 mm. In its stomach is a skink (*Lygosoma pectorale*) measuring 49 mm. from snout to anus.

CYCLORANA AUSTRALIS (Gray)

Alytes australis Gray, 1842, Zool. Misc., 56: North coast of Australia, *i.e.*, Port Essington, Northern Territory, Australia.

2 (M.C.Z. 26002), McMillans, near Darwin.

These juvenile forms are so shrivelled by immersion in strong formalin that their habits might be described as "slender", *i.e.*, in this respect referable to *alboguttatus* (Günther) of Parker's (1940, 16) key, which differentiates the two species as follows:

Zygomatic process of the squamosal heavily sculptured and forming a broad suture with the maxilla. Habitus stout	*australis*
Zygomatic process not sculptured and separated from the maxilla, or only very narrowly in contact with it. Habitus slender	*alboguttatus*

But Parker (1940, 20) is mistaken in referring part of my (1935, 13) *alboguttatus* to the synonymy of *australis* and suggesting that the frog (M.C.Z. 11647) from Alexandra (*not* Alexandria), Northern Territory, is really an *australis*. It is true that the frog was received from the British Museum in 1925 as "*Phractops australis*" (presumably identified by Boulenger), but both in zygomatic structure and colour pattern it agrees with *alboguttatus*. That the British Museum skeleton of another frog taken at Alexandra by the same collector happens to be *australis* is interesting, for Parker records both species as occurring at Port Denison, Queensland. Despite their close relationship the two species are quite distinct.

The larger frog measured 45 mm. and was taken in a ditch of stagnant water about six miles north of Darwin, the smaller was in sand behind the beach at Lee Point about ten miles north of the town (T. R. T.).

LIMNODYNASTES CONVEXIUSCULUS (Macleay)

Ranaster convexiusculus Macleay, 1828, Proc Linn Soc. N.S.W., **2**, 135,: Katow, *i.e.*, Binaturi River, Dutch New Guinea.

5 (M.C.Z. 26003-7), near Darwin.

Vomerine teeth extending well beyond lateral borders of choanae; first and second fingers subequal; inner metacarpal tubercle slightly longer than the second; a single metatarsal tubercle which is not shovel-shaped. Largest (M.C.Z. 26003) measures 50 mm.

In life: Above, marbled with black and grey; the spots sometimes finely edged with white. Below, white vermiculated (with brown). (T. R. T.)

This species has been recorded already from Darwin by Parker (1940, 54). As he has seen the type of *L. olivaceus* De Vis, which he refers to the synonymy of *convexiusculus*, it must be assumed that De Vis' description of *olivaceus* as having two metatarsal tubercles is erroneous. Parker is quite correct in concluding my (1935, 19) *L. salmini* Steindachner is a composite, for both Queensland frogs (M.C.Z. 3610, 3623) conform to his new definition of *convexiusculus*.

UPEROLEIA RUGOSA (Andersson)

Pseudophryne rugosa Andersson, 1916, Svenska Vetensk.-Aka. Handl., **52**, No. 9, 31; pl. i, fig. 4: Colosseum, southern Queensland.

1 (M.C.Z. 25991), Noonamah.

If correctly identified, this 18 mm. juvenile is the first example of *rugosa* to be recorded from the Northern Territory. Also the first of its species in the Museum of Comparative Zoölogy, for I (1935, 31) erred in making *rugosa* a subspecies of *marmorata* and the five frogs then referred to *U. m. rugosa* are simply *marmorata*. As the ranges are largely co-extensive, Parker (1940, 70) did not detect my mistake and the citation on his p. 70 should be transferred to p. 69.

CRINIA SIGNIFERA SIGNIFERA Girard

Crinia (Ranidella) signifera Girard, 1853, Proc. Acad. Nat. Sci. Philadelphia, **6**, 421: "New Holland," *i.e.*, Australia.

8 (M.C.Z. 35999-26000) Knuckey's Lagoon.

All are juvenile, the largest measuring only 12 mm. Six of them were taken beneath a pandanus trunk (T. R. T.).

This is the form to which Darwin frogs are referred by Parker (1940, 87), whose synonymizing of my 1935 references is probably correct, for I utilised or stressed other characters in defining the species of this difficult genus which he has so thoroughly revised.

Hyla caerulea (Shaw)

Rana caerulea Shaw, in White, Journ. Voyage N.S.W., App., 248, pl. ——: New South Wales.

4 (M.C.Z. 25992-3), Berrima.

Vomerine teeth between the posterior borders of the choanae, from which they are well separated: head as long as, or shorter than, broad; snout once and a half as long as eye; tympanum two-thirds to seven-eighths the orbital diameter; outer finger half webbed; heel of adpressed hind limb reaches the tympanum or eye. Length of ♂ (M.C.Z. 25992), 72 mm., of ♀, 74 mm.

The largest was taken at night on rocky ground, the others between sheets of galvanised iron at Larrakeyah Barracks (T. R. T.).

Hyla rubella Gray

Hyla rubella Gray, 1842, Zool. Misc., 57: Port Essington, Northern Territory, Australia.

♀ (M.C.Z. 23998), Knuckey's Lagoon.

Vomerine teeth between the posterior borders of the choanae: head *longer* than broad; snout *once and a half* as long as eye; tympanum two-thirds the orbital diameter; outer finger without web; heel of adpressed hind limb reaches shoulder. Length of gravid ♀, 32 mm.

Hyla aurea (Lesson)

Rana aurea Lesson, 1830, Zool. in Duperrey, Voyage autour du Monde . . . sur . . . La Coquille, 2, 60, pl. vii, fig. 2: Macquarrie and Bathurst Rivers, New South Wales.

5 (M.C.Z. 25994-5), Knuckey's Lagoon.

Vomerine teeth between the choanae; head as long as, or longer than, broad; snout once and a half as long as eye; tympanum three-quarters of, or equal to, the orbital diameter; outer finger without web. Too shrivelled to be worth measuring.

Hyla nasuta (Gray)

Pelodytes nasuta Gray, 1842, Zool. Misc., 56: Port Essington, Northern Territory, Australia.

2 (M.C.Z. 26001), near Darwin.

Vomerine teeth between the choanae; head much longer than broad; snout twice as long as the eye; tympanum seven-eighths, or equal to, the orbital diameter; outer finger without web; heel of the adpressed hind limb reaches beyond tip of snout. Larger measures 43 mm.

In life greenish-black with a broad brown stripe down centre of back. Found among leaves after burning of spear grass at McMillan's, about six miles from Darwin (T. R. T.).

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THE ECOLOGY OF THE WESTERN CLARE HILLS, SOUTH AUSTRALIA

By C. D. Boomsma

Summary

The object of this paper is to describe the ecology of the E. macrorryncha and related associations, since little has been published on its occurrence in South Australia. A description of a fibrous-barked eucalypt in a personal communication by Mr. C. B. Scarfe led to a field examination in the Clare district. The eucalypt was located and it proved to be E. macrorryncha, thus constituting a re-discovery, since Tate records it for this district in his notebook in 1889, which is the same as his Adelaide district in hi Flora of South Australia of 1890. Later, in 1907, Maiden (6) briefly acknowledged Tate in recording its occurrence for the Adelaide district, but after a field excursion he denied its presence in 1909 (7). Black (1), in 1926, followed suit by omitting to record it, but Blakely (2), in 1934, records it for the Adelaide district. Similarly, it is not recorded in the most recent work by Burbidge (3).

THE ECOLOGY OF THE WESTERN CLARE HILLS, SOUTH AUSTRALIA

With Special Reference to the Disjunct Occurrence of E. macrorryncha (F. v. M.)

By C. D. Boomsma *

[Read October 14 1948]

The object of this paper is to describe the ecology of the *E. macrorryncha* and related associations, since little has been published on its occurrence in South Australia. A description of a fibrous-barked eucalypt in a personal communication by Mr. C. B. Scarfe led to a field examination in the Clare district. The eucalypt was located and it proved to be *E. macrorryncha*, thus constituting a rediscovery, since Tate records it for this district in his notebook in 1889, which is the same as his Adelaide district in his Flora of South Australia of 1890. Later, in 1907, Maiden (6) briefly acknowledged Tate in recording its occurrence for the Adelaide district, but after a field excursion he denied its presence in 1909 (7). Black (1), in 1926, followed suit by omitting to record it, but Blakely (2), in 1934, records it for the Adelaide district. Similarly, it is not recorded in the most recent work by Burbidge (3).

The area comprises 40 square miles of range country, being the western half of the Hundred of Clare, lying directly west of the main Adelaide to Clare road. *E. macrorryncha* is limited to the uplands east of the divide. See fig. 1 and 2. The divide has an elevation of 1,500 feet; a few peaks are higher, and it is dissected by many small valleys formed by the winter-flowing tributaries of the Hutt River. Valley formation has been slow, so the topography is accordingly rugged and surface run-off is rapid.

In the main, the bedrock is of Proterozoic age and is quartzite or sandstone with limited occurrence of argillaceous rocks. The general strike is north and south, as shown by the north-south direction of the axis of the range. Intermittent winter springs were observed which may indicate fault zones, otherwise no faults were observed.

CLIMATE

Rainfall—The rainfall is mainly derived from the normal winter rains due to the general west to east movement of the pressure systems, with infrequent heavy summer rains due to tropical troughs from the north. The mean annual rainfall in the ranges is 27 inches, with 19 inches in the winter six months and 8 inches in the summer six months. It is probable that this rugged topography produces local rain-shadows with rainfalls up to 30 inches per annum. High summer temperatures are frequent and severe frosts are common. The frosts may be experienced during a period of seven months of the year. In general, the climate is cold and wet in winter, warm and dry with occasional frost in early summer.

SOILS

Field observations show that the soils are, in general, shallow; skeletal soils are frequent in occurrence, and deeper transported soils are limited to the broader Hutt River valley. Slight podsolisation is general, as most of the soils have a grey sandy-loam surface horizon and up to 20 inches of slightly oxidised clays in the lower horizon. Occasionally a red-brown clay is observed with bed rock at less than 36 inches.

Laterite, a feature of the Mount Lofty Ranges, 60 miles to the south, is lacking, as are swamp soils, heavy loams and calcareous soils. The latter is due to the absence of calcareous bedrock. All the soils are well drained.

* Forestry Department, Adelaide.

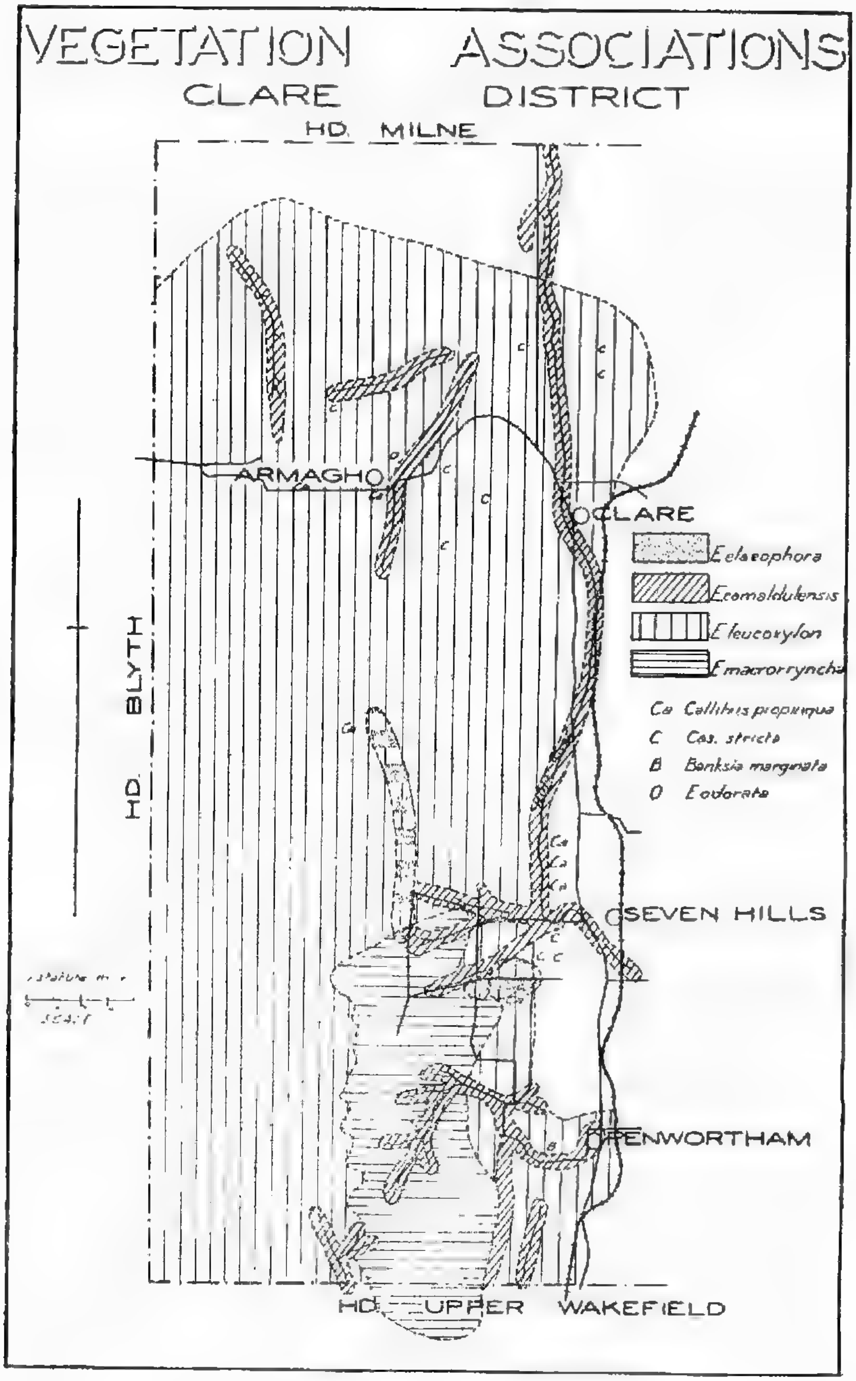

Fig. 1

VEGETATION

Floristics—The nomenclature of eucalypts is after Blakely (2) and that of the other species after Black (1). The floristic make-up of the understorey is continuous in all the forest types, being composed of occasional scattered trees of *Casuarina stricta*, *Callitris propinqua*, *Acacia pycnantha*, and *Exocarpus cupressiformis; Bursaria spinosa*, *Acacia Wattsiana*, *Hibbertia stricta*, and *Lissanthe*

strigosa are the chief shrubs. The commonest geophyte is *Thysanotus dichotomus*, and the characteristic ground cover of grasses consists of *Themeda australis*, *Danthonia* spp. and *Stipa* spp. Leguminous shrubs are missing quite frequently from the understorey, which is unusual when there is a stringybark dominant.

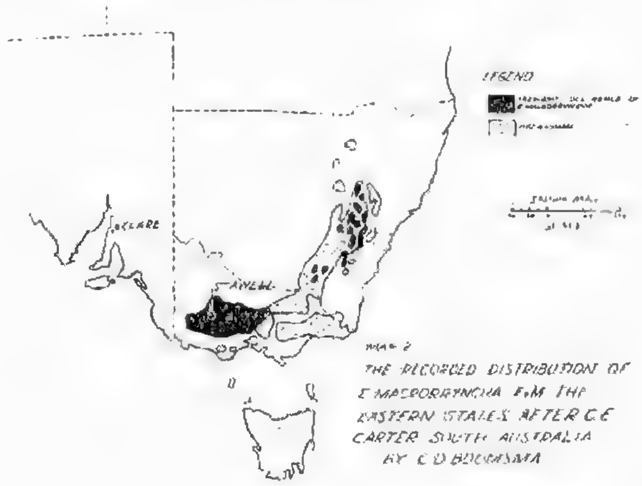

Fig. 2

Associations—Those present are all dominated by the eucalypts *E. camaldulensis*, *E. leucoxylon*, *E. elaeophora* and *E. macrorryncha*. There was no *E. odorata*, *E. fasciculosa* or mallee present. A stray *E. calcicultrix* was observed in the Clare Picnic Ground, adjacent to the main road. Stands with more than one eucalypt species as dominants are frequent, but *E. leucoxylon* is typical of the drier exposed portions, *E. camaldulensis* of the moister valleys with higher fertility, *E. macrorryncha* on the wetter, cooler uplands, and *E. elaeophora* supplanting *E. camaldulensis* on the higher fertility sites with greater exposure. As no distinct boundaries between sites occur, it is not surprising that several eucalypt species are found competing for dominance. It is therefore expected that the degree of variation in the factors of the environment is greater than that tolerated by any one species.

The associations are all savannah woodlands with a variable number from one to a hundred trees per acre.

E. leucoxylon association—This association occupies the greatest area, being a part of the continuous distribution along the coast side of the Mount Lofty Ranges from Adelaide to Quorn. In the area described it occurs on both the western and eastern slopes as a dominant, with occasional inlying islands of *Casuarina stricta* and *E. elaeophora*. The ground cover is grassy, often bare on skeletal soils, and the dominant is only a medium-sized tree, having a small crooked stem up to 30 inches in diameter. The number of trees per acre varies from under ten to a hundred, depending on the amount of clearing, grazing, burning and the size of the trees.

E. camaldulensis association—This is typical of the valleys which have deep, fertile, transported soils. The trees may reach a gross size up to 48 inches in diameter, heights up to 80 feet are common, but regeneration is slower than utilisation and the present occurrence is only a remnant of the original stand. The understorey is typically grasses, with a few bulbs, and occasionally *Casuarina stricta*, *Acacia pycnantha*, *Acacia rhetinodes* and *Bursaria spinosa*. Near Penwortham, *Banksia marginata* is in the understorey.

E. elaeophora association—This species is rarely an exclusive dominant on areas greater than 5 acres in extent. It is found with *E. leucoxylon* or *E. macrorryncha*, and again the understorey is continuous with neighbouring associations. When it is found in valleys the soils are less fertile and it is later replaced by *E. camaldulensis* lower down the valley where the soils are more fertile.

E. macrorryncha association—This association is now mainly a savannah woodland, but the ridge-top parts of Sections 364, 365, 436, 535 and 536 have *Xanthorrhoea quadrangulata* and *Lissanthe strigosa* in the understorey with a grassy ground cover. The absence of legumes and Proteaceae is marked, and this community can be classed as a gradation between savannah woodland and dry sclerophyll forest. The understorey is composed of scattered shrubs of *Bursaria spinosa* and *Acacia pycnantha*, with a few herbs *Hibbertia stricta*, *Acaena sanguisorbae* and a grassy ground cover.

The present facies of the *E. macrorryncha* association in this district is similar to that of the *E. leucoxylon* and *E. camaldulensis* association. The understoreys are continuous with the exception of the restricted occurrence of the *Xanthorrhoea quadrangulata* understorey already mentioned. However, this understorey occurs in other woodland associations in other districts of South Australia.

The distribution of *E. macrorryncha* in the eastern States of Australia is after Carter (4). See fig. 2. Ecologists have described its field relations, notably Pryor (9) in 1939, who states that it reaches its best development as a consociation on exposed upland sites of 2-3,000 feet altitude in the Australian Capital Territory. Associated eucalypts are *E. Rossii*, *E. maculosa* and *E. cordieri*. The understorey is considerably better developed there than in South Australia and includes the tall shrubs *Pomaderris elliptica*, *Acacia falciformis* and *Exocarpus cupressiformis*. Abundant small shrubs, mainly epacrids and legumes with *Xanthorrhoea australis* ensure an almost continuous ground cover. In Victoria, Ewart (5) in 1925 and Petrie et al (8) in 1929, describe it as the dominant of a consociation on exposed upland sites on the Silurian formation at altitudes of 2-3,000 feet. These occurrences are comparable with each other in the broader characteristics. The nearest recorded occurrence of *E. macrorryncha* to this area is at Stawell, 300 miles to the east in Victoria. As an isolated duplicate, genetic origin is highly improbable; the restricted occurrence of this species requires a knowledge of the methods of colonisation and invasion of eucalypts since early Pleistocene times. Similar disjunct occurrences have been recorded for *E. hemiphloia*, *E. albens*, *E. microcarpa*, *E. pauciflora*, *E. rubida*, *E. cladocalyx* and *E. ovata*.

It is highly improbable that the Hundred of Clare contains the only suitable site for *E. macrorryncha* in South Australia, and so the alternatives are that this is a relict of a previously wider occurrence or that it occurs elsewhere and has not yet been observed or that it is a recent arrival and has not spread.

The association is not vigorous since it has not extended its boundaries in sixty years but rather has contracted, due to death of mature trees and absence of seedlings to maintain dominance along the boundaries. To this extent the field observations favour the theory that it is a relict. Although occurrences elsewhere in South Australia are possible, they are improbable.

It is noteworthy that all the factors which favour the status of a relict strongly argue against this species being a new arrival.

SUMMARY

The rediscovery of the occurrence of *E. macrorryncha* in the Clare Hills, which is the only recorded area in South Australia, has led to mapping the occurrence with a description of the environment and community relations.

The disjunct occurrence of *E. macrorryncha* 300 miles from the nearest recorded occurrence in the east at Stawell is difficult to explain. The explanation depends on the past climatic changes which may have destroyed connecting sites between the east, leaving this occurrence in the ranges as a relict.

Other species with similar field occurrences are *E. albens, E. hemiphloia* and *E. microcarpa*.

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NOMENCLATURE OF EUCALYPTS WITH SPECIAL REFERENCE TO TAXONOMIC PROBLEMS IN SOUTH AUSTRALIA

By C. D. Boomsma

Summary

The identification of eucalypts has always been a task requiring all the faculties of judgment, and even then, numerous contentious issues arise which persist without a satisfactory explanation. Such an issue is the identification and naming of specimens which have some characters common to at least two species; or a gradual variation of a single character from one specimen to another. In fact, variation is so general that the limits require definition, but to do so involves a major statistical examination on the four following variations: - Variations of a single organ during maturation; variations of an organ on a single tree; variations of an organ between trees, including (a) variations due to environmental causes and (b) variations due to genetic causes; variations between species.

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[Read 14 October 1948]

The identification of eucalypts has always been a task requiring all the faculties of judgment, and even then, numerous contentious issues arise which persist without a satisfactory explanation. Such an issue is the identification and naming of specimens which have some characters common to at least two species: or a gradual variation of a single character from one specimen to another. In fact, variation is so general that the limits require definition, but to do so involves a major statistical examination on the four following variations:—Variations of a single organ during maturation; variations of an organ on a single tree; variations of an organ between trees, including (a) variations due to environmental causes and (b) variations due to genetic causes; variations between species.

Variations of a Single Organ during Maturation

The main importance of the stage of maturity of an organ to those engaged in the determination of species is the ability to recognise a given stage and describe it correctly. Juvenile leaf characters, for example, afford a ready means for identifying some species, and this character may be used to separate or show alliances between species. But rates of maturation vary and even an individual season will determine the length of flowering period, character of nectar production and the beginning of shoot growth, so this class of variation is least understood.

Variations of an Organ on a Single Tree

It is known and accepted that variations occur, but just how great has not been reliably determined. It is to be expected that the variation within a tree would be less than between trees, and in the case of *E. obliqua* this is borne out by a statistical examination of capsule dimensions carried out by the author.

Variation of an Organ between Trees

It is known that variations are great, but the limits have not been determined. The amount of variation is apparently least in endemics to South Australia, particularly those restricted in area, for example *E. cladocalyx*, *E. cosmophylla*, *E. cneorifolia*, *E. fasciculosa* and *E. remota*. On the other hand species with a wide distribution, including areas at the limits of the specific ecological amplitude of the species, generally show a correspondingly wide variation in the character of any one organ. The causes appear to be partly environmental and partly genetic. Species which show wide variations include *E. oleosa*, *E. anceps*, *E. leucoxylon*, *E. odorata*, *E. Huberiana*, *E. Baxteri*, *E. obliqua*, and *E. leptophylla*. The variations are diverse and different botanists have given varietal and even specific rank to specimens showing characters which only represent one stage in a sequence of characters from one species to another. This confusion has been accentuated by the practice of taking a small sample of a tree and raising it to the exalted position of a "type" with which all future specific determinations must be compared. In material showing wide variation, the paradox is reached that the more closely a single specimen is described for specific rank, the more

* Forestry Department, Adelaide.

likely is it that an identification key will be unworkable. In South Australia, at least half the total number of species exhibit such wide variation in characters that the existence of intermediate forms between two species must be accepted.

(a) *Variations due to environmental causes.* Generally a species possesses a wider potential environment than is exhibited in its natural distribution; for example, *E. cladocalyx* can be grown on solonized brown soils in the 12" mean annual rainfall of Loxton, although its best natural occurrence is in the Flinders Ranges on podsols with at least 25" mean annual rainfall. Furthermore, descriptions of characteristic environments for a species are fragmentary and the limits of both potential and natural environments have to be defined, so that to describe variations of character in organs due to environmental causes can only be based on speculation.

However, variations in ecological character due to environmental causes, *i.e.*, stem form, frequency of occurrence and exclusiveness are frequently encountered. Such variations are common to all plant species and need not be detailed here other than to remark that variations are correlated with the diversity of environments occupied by any one species, so that *E. leucoxylon* and *E. oleosa*, two widely occurring species, show many variations due to environmental causes. It would be expected that variations in ecological character would be at a minimum in large areas of constant environmental character. So far, no such large area has been encountered in South Australia, and it is unlikely that such an area exists in the tree zone.

(b) *Variations due to genetic causes.* This question is intimately related to that discussed in the following section. Maiden (4) in 1922 summarised the evidence for genetic variation, and stated that intermediate forms occurred between many eucalypt species. Furthermore, he described several plants as natural hybrids. In South Australia it is probable that *E. jugalis* (Naudin) is of hybrid origin, while *E. Kalangadooensis* (M) and *E. McIntyrensis* (M) are also probably hybrids. In 1946, Brett (2) showed that gradations arise by selfing of the F1 generation and occasional back-crosses to the original parents. Some members of such a swarm of individuals will be more suited to the site than others and so will produce a stand of trees with a wide (but determinate) range of characters. As time progresses, fixation of characters may occur to give rise to a hybrid-polymorph. The stages from the hybrid-swarm to the hybrid polymorph are conjectural, but field observations support such a view. It is possible, then, that polymorphs may produce new biotypes, *i.e.*, collections of individuals breeding true for characters of taxonomic importance, and with a narrow determinate variation of characters. No attempt has yet been made to define a species on such a basis, so it is a matter of opinion when the amount of variation shown by a polymorph is sufficient to be accepted as a species or biotype. It should be noted that no two individuals are identical in genetic character, which explains the difficulty encountered in identification of material collected from areas where hybrid swarms occur.

Variations of an Organ between Species

Interspecific variation is probably of genetic origin and the study of gradations between species is greatly facilitated by the theory of hybridism, and the segregation which is continuing in some cases to the present day. Eucalypt species in South Australia do not all show segregation, but the probability of observing genetic variation is highest amongst the widely occurring species. Observations suggesting genetic relationships between species are set out in the following notes, but first the scope of specific sequences in juvenile and mature leaves, buds and capsules, illustrated in the figures, should be examined. The nomenclature is after Blakely (1).

Fig. 1-4 show a specific sequence in the juvenile leaf shapes of *E. Huberiana.*
Fig. 5-9 show an interspecific sequence between *E. viminalis* (fig. 5), *E. Huberiana* (fig. 7), and *E. leucoxylon* (fig. 9).

Fig. 1-4 show a specific sequence in juvenile leaf shape in *E. Huberiana;* fig. 11-18 show a portion of the mature leaf-shape sequence in *E. transcontinentalis;* fig. 23, 24, 27, 28 and 32 show sequences of bud characters, while fig. 25 and 26 show the range of sizes and shapes encountered in *E. leucoxylon* capsules. Fig. 40 shows the diversity of capsule characters in *E. Baxteri,* and fig. 39 shows a large-fruited form of *E. Huberiana.*

Evidence of interspecific sequences may be had from two sources. One is the published data (the most recent being that of Burbidge (3)), and the other may be obtained from the field. From the first source there is general agreement that many difficulties in nomenclature are due to interspecific genetic variation, and numerous examples are given by the authors already referred to.

Only a few of the sequences observed in the field have been illustrated and the most familiar will be discussed. From the small area of ten acres in the Hundred of Coonarie, specimens comprising fig. 29 were obtained. Fig. 29a has buds that compare favourably with those of *E. leptophylla,* but its leaves are up to ten centimetres long and two cm. wide and agree with those of the nearby *E. oleosa.* Fig. 29b has buds about twice the size of those of 29a, and agree with those of a type specimen of *E. socialis* in the National Herbarium, Melbourne. The elongated conical operculum of fig. 29c and the small waisted type of fig. 29d are steps to fig. 29e, which is similar to the operculum of *E. transcontinentalis.* If the examples do not represent species but varieties, the position is

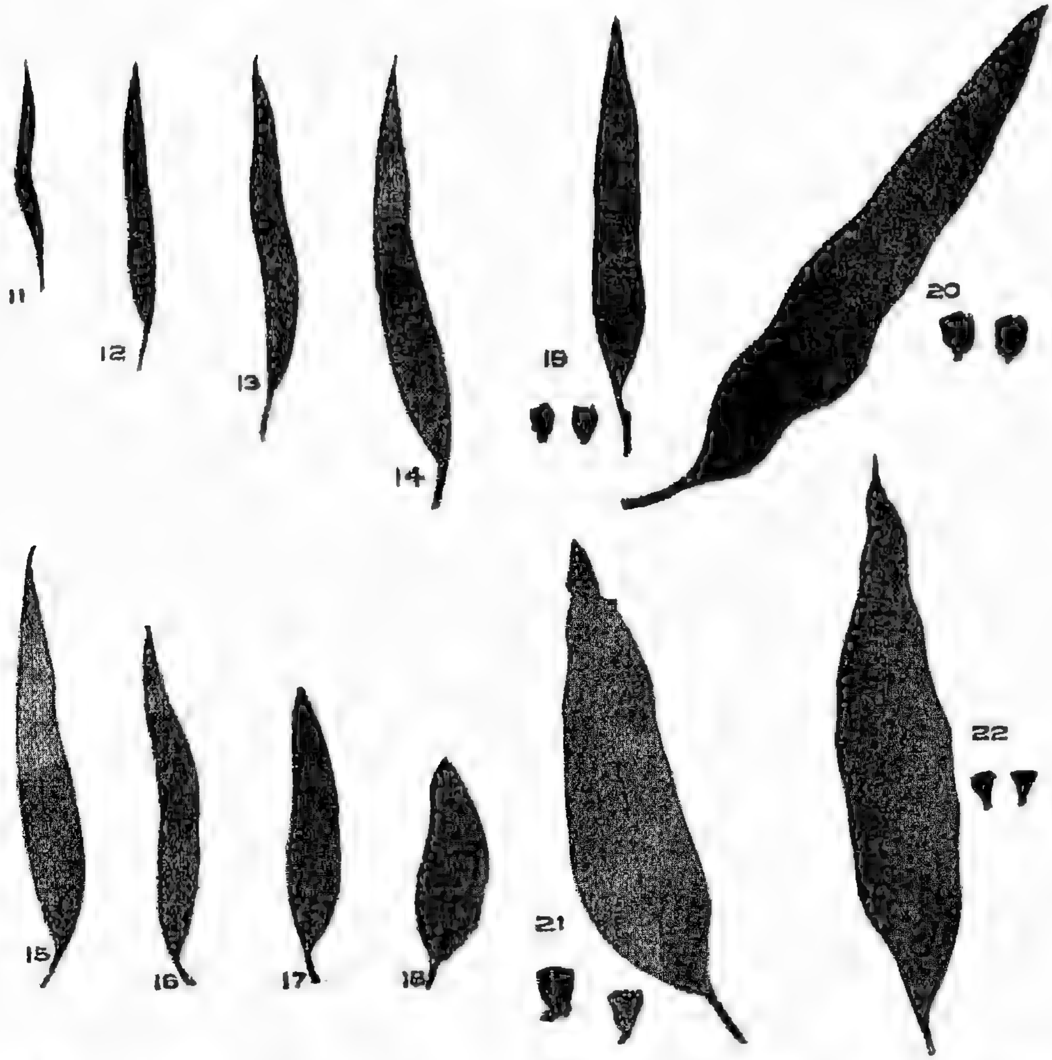


Fig. 11-18 show a specific sequence in mature leaf shape of *E. transcontinentalis*.
Fig. 19-22 show an interspecific sequence in mature leaf shape and capsules between *E. Huberiana* (fig. 19) and *E. ovata* (fig. 22). Fig. 20 and 21 are intermediate forms.

unimproved and the acceptance of numerous forms would be misleading. In this occurrence the field suggests that this is a hybrid swarm as variations were also collected of *E. diversifolia, E. rugosa* and *E. leptophylla*.

Interspecific sequences have also been observed in *E. odorata*, but these are not quite so obvious, so that difficulty is experienced in separating *E. calcicultrix, E. odorata, E. Lansdowneana* and *E. jugalis*. Fig. 33-35 show the similarity of the capsules.

E. viminalis has often been observed in an interspecific sequence with *E. leucoxylon*, as seen in fig. 5-9, which include a few steps of the juvenile leaf shape sequence between the two species. On the same small area, specimens were collected with triphylly and alternate leaves. See fig. 42 and 43.

E. leucoxylon is widely scattered and is concerned in many interspecific sequences. Fig. 5-9 show an interspecific sequence between *E. leucoxylon* and *E. Huberiana*. *E. leucoxylon* is closely associated with *E. jugalis* in the Yatina district and specimens occur which are difficult to separate into species. Other examples of genetic variation occur in *E. leucoxylon*, such as the sequence between *E. leucoxylon* and *E. calcicultrix* near Cape Jervis, and specimens with more than three buds per umbel from the Meningie district. See fig. 41.

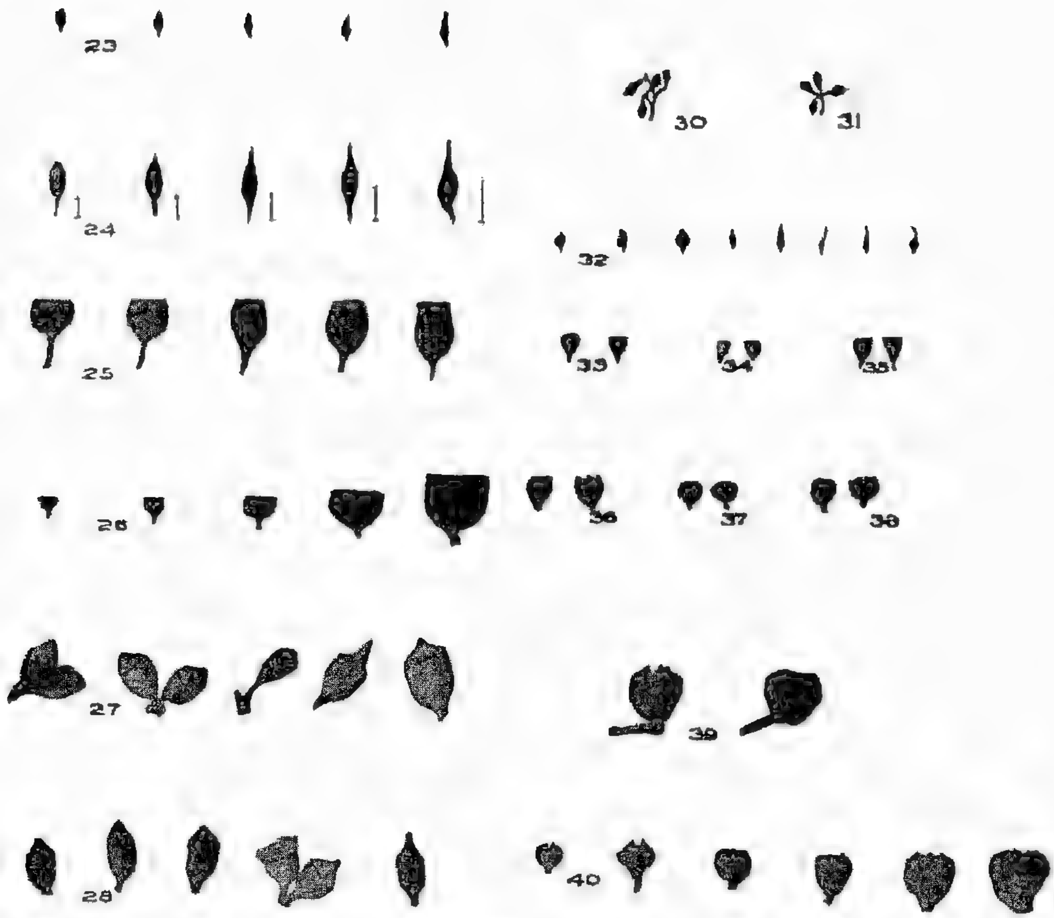


Fig. 23-24 show portion of the specific sequences in operculum shapes of *E. oleosa* (fig. 23) and *E. transcontinentalis* (fig. 24).

Fig. 25-26 show specific sequences in size and shape of capsules of *E. leucoxylon.*

Fig. 27-28 show specific sequences in size and shape in the buds of *E. cosmophylla.*

Fig. 30-31 show an interspecific similarity between buds of *E. bicolor* and *E. intertexta* respectively.

Fig. 32 shows a specific sequence in operculum shape of buds of *E. camaldulensis.*

Fig. 33-35 show the interspecific similarity of capsules of *E. odorata*, *E. jugalis* and *E. microcarpa* respectively.

Fig. 36-38 show an interspecific similarity between capsules of *E. viminalis*, *E. rubida* and *E. Huberiana* respectively.

Fig. 39 shows a large capsule form of *E. Huberiana.*

Fig. 40 shows the diversity of character in capsules of *E. Baxteri.*

Examples from other species such as *E. jugalis, E. elaeophora* and *E. Huberiana* have been collected and not figured. It is evident that these sequences indicate relationships between species, and from the nature of the sequence and from authorities already referred to, Table I has been compiled. The purpose of compiling the table is to indicate the species relationship in South Australia. The groups are naturally subdivided, so that there is little chance of observing an interspecific sequence between species of two groups and the order of each species is to some extent arbitrary, but the probability of two adjacent species forming sequences is higher than in those distantly connected. It is to be noted that the table contains some species that are of reputed hybrid origin, such as *E. jugalis, E. unialata, E. Huberiana, E. vitrea* and *E. anceps.* Interspecific

Fig. 29 shows some genetic variants of *E. oleosa*.
Fig. 41 shows an umbel of *E. leucoxylon* containing more than three buds.
Fig. 42 shows triphylly in *E. viminalis*.
Fig. 43 shows alternate juvenile leaf arrangement of *E. viminalis*.
Fig. 44 shows an umbel of buds of *E. cosmophylla* containing more than three buds.

sequences help to emphasise the relationships of species within each group, so that it is proposed that a study of these sequences will be of considerable use in the identification of species.

Summary

The identification of species of the large genus Eucalyptus (more than 500 species) is complicated by the occurrence of many forms that are atypical. Some of these forms are genetic variants and are of hybrid origin.

A selection of examples that occur in South Australia is figured and some interspecific sequences are discussed. These sequences are of use in confirming species relationships in groups as an aid to identification.

Interspecific sequences are frequently observed in widespread species, but not in endemics.

References

1 Blakely, W. F. 1934 "Key to the Eucalypts"

2 Brett, R. G. 1946 "Some Aspects of Hybridisation in relation to Taxonomy in Eucalypts". Unpublished paper. Section M., Aust. N.Z. Adv. Science

3 Burbidge, N. T. 1947 Trans. Roy. Soc. S. Aust., 71, (2)

4 Maiden, J. H. 1922 "Critical Revision of the Genus Eucalyptus"

Table I

Showing the Taxonomic Relationships in the Genus *Eucalyptus* in South Australia

	vitrea			
pauciflora	de Beuzevillei x			
	niphophils x			
camaldulensis	rudis x			
	umbellata x			
	Morrisii			
	anceps		rugosa	
dumosa	pileata	brachycalyx	conglobata	
	incrassata	tetraptera x		
	Blaxlandi x			
Baxteri	capitellata x		obliqua	
		diversifolia	remota	
	sideroxylon	fruticetorum	viridis	
leucoxylon	calcicultrix	odorata	microcarpa	hemiphloia
	jugalis	Lansdowneana		albens
	elaeophora			
	Huberiana	viminalis	rubida	Dalrympleana x
	ovata	unialata x	globulus x	bicostata x
	cneorifolia			
oleosa	transcontinentalis	Gillii	Flocktoniae	

x denotes interstate species

THE GEOLOGY OF THE BOOLCOOMATA GRANITE

By A. W. Whittle

Summary

Old Boolcoomata Station is situated approximately 280 miles north-east of Adelaide, and 12 miles north of Olary, which is on the railway line to Broken Hill. A very great portion of the area of the Station is occupied by interesting granitic rocks and associated gneisses. These rock types occur amongst a normal folded sedimentary series of argillaceous and quartzitic rocks.

THE GEOLOGY OF THE BOOLCOOMATA GRANITE

By A. W. WHITTLE *

[Read 14 October 1948]

I. INTRODUCTION

Old Boolcoomata Station is situated approximately 280 miles north-east of Adelaide, and 12 miles north of Olary, which is on the railway line to Broken Hill. A very great portion of the area of the Station is occupied by interesting granitic rocks and associated gneisses. These rock types occur amongst a normal folded sedimentary series of argillaceous and quartzitic rocks.

Previous Work

The first important contribution to the geological study of the north-eastern portion of South Australia was that published in 1912 by Sir Douglas Mawson, Professor of Geology at the University of Adelaide. This work, which covered a large area including the district in which the present work was done, was published as a Royal Society Memoir. Subsequently Sir Douglas Mawson has continued his study of this region, including much detailed field work and petrological analysis in the Olary district. A list of investigations by other workers is given in the bibliography.

The present investigation was carried out to determine the nature of the Old Boolcoomata Granite and its relation to the sediments which it intrudes. An attempt was also made to discover some data which might suggest whether this granite is the result of an intrusion or of the process known as granitization.

The area of the batholith examined measures three miles east and west, by two miles north and south. Low rounded hills of igneous and gneissic rocks, with a few large bare granite hills, make up the landscape. Traverses were made across it in a north-south direction at quarter mile intervals, to pick up the distribution of rock types and to ascertain the position of contacts between them. Subsequently, several of these contacts were followed to prove continuity between the positions located by traversing.

Although there is a great diversity of rock types in the batholith, they may be conveniently considered in three main groups. These are (1) a medium to coarse-grained muscovite granite, (2) a finer-grained, somewhat gneissic porphyritic felspar granite, (3) granitic rocks in which the presence of injection gneisses is significant. The distribution of these groups may be seen on the folded map.

* Mines Department.

II. THE PRINCIPAL GRANITE PHASE

There are three areas in which this is the dominant rock type, two of which are partly made up of patchy developments of the porphyritic felspar granite.

The principal granite area extends three-quarters of a mile north from the station house and is then replaced by gneissic rocks. To the west it runs against alluvium and the contact with the slates, while its greatest extent is eastward, where it runs uninterrupted down towards Binberrie Hill. Throughout this area, medium to coarse-grained felspar-rich granite is the dominant rock. The rock is mostly massive, but becomes slightly gneissic in places, particularly towards the northern border of the belt. Jointing is well developed in two major directions at right angles, while a minor third direction is sometimes present. The joint planes usually have steep dips. These features produce excellent "tor" structures with occasional balanced boulders.

Sheeting structure occurs in large outcrops where a series of fractures have formed separated by several feet and lying parallel to the rock surfaces. In a large exposure, such as the slope of a hillside, a series of steps develops as overlying sheets are weathered away, leaving the immediately underlying pavement strewn with decaying granite boulders. These pavements are large, smooth and gently rounded, and have resulted from the expansion of felspars undergoing kaolinization as well as by the alternate heating and cooling of the granite by day and night.

Erosion of the area is greatly assisted by the joint system, because these fractures start streamlets running along well-established channels which are obviously scoured-out joint fissures. Similarly, the major streams which drain the granite hills trend roughly parallel to one or other of the major jointing directions.

Pegmatite veins, up to two or three feet wide, in general follow the N.W.-S.E. direction of jointing, which suggests that the fissures are pre-pegmatite, developed in the early stages of the formation of the batholith, providing an easy means of escape for the pegmatitic materials developed in the late stages of consolidation of the granite. Probably these fractures, carrying pegmaties up to three feet wide, were enlarged by remelting along their margins, because there is a gradation in grain size between the pegmatites and the enclosing granite. This, however, may be the result of a chilling of the pegmatite along its margins.

The granite breccia (referred to later) trends parallel to the E.-W. joint system and may therefore be related to the jointing. Naturally, accumulated stresses would most readily be relieved along an already well-established fracture system. Movement has occurred along some planes of jointing, shown by the local faulting of minor and major pegmatites. These joints post-date the pegmatites they offset, and belong to a different system from those along which the pegmatites moved. These joints may be related to the brecciation.

The joints change direction toward the western portion of the main granitic belt, and the associated pegmatites swing round to an almost westerly trend. These lineal pegmatites are very abundant in the granite, half a mile N.-E. of the homestead. They are narrow, but extend many hundreds of yards east and west. East and west of this locality, the lineal pegmatites are replaced by discontinuous wider irregular pegmatites which show no structural control. The pegmatites are coarse-grained, rich in felspar, and poor in micas and accessories, although tourmaline is abundant in some.

An interesting feature of this granitic belt is the granite breccia, made up of angular granite fragments up to several feet in size, set in a fine-grained dark matrix largely composed of crushed clayey felspars, quartz and mica. The large

broken boulders are all of the same type, *viz.*, a granite identical with that making up the major granitic zones. There are occasional slate or quartzite boulders within the breccia, presumably, broken xenolithic material. In places there are denuded surfaces resembling crazy pavements where the nature of the breccia can be closely studied (pl. xx, fig. 7). Where angular boulders are absent, larger grains in the matrix are streaked out into parallel rows set in finer mylonitic

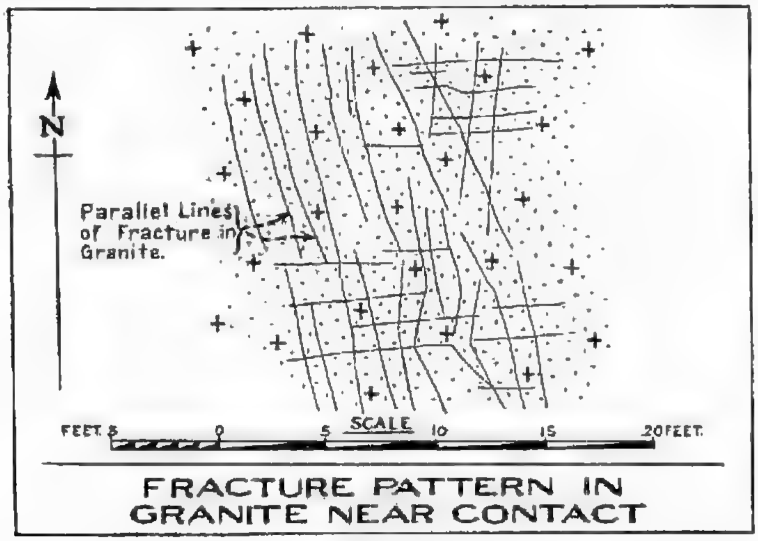


Fig. 1
Fracture pattern in granite near its contact with the granite breccia.

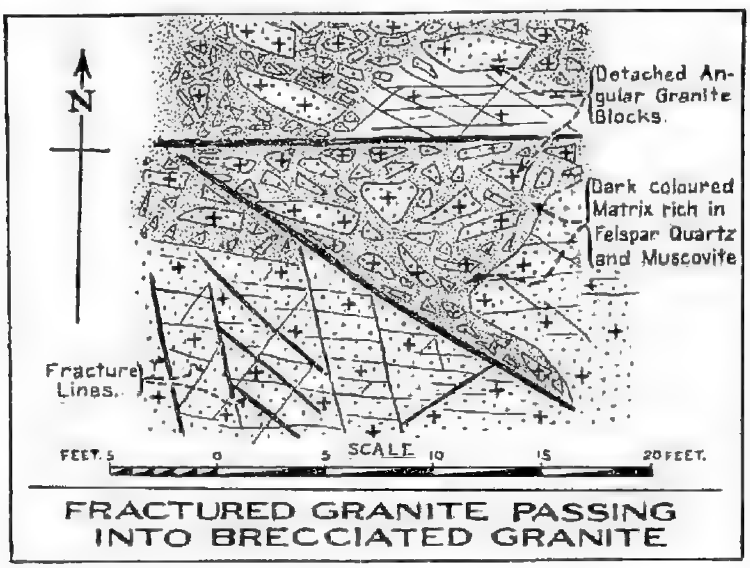


Fig. 2
Fractured granite passing into brecciated granite.

material, producing a "pseudo-bedding" effect, by the freak "sorting" of grains. Most of the breccia carries angular boulders but there is much variation, thus between wide bands containing granite boulders there are these "bedded" zones with a fine-grained matrix set with parallel rows of rolled-out rounded granite or felspar grains which are porphyroclastic remnants of pre-existent granite (pl. xx, fig. 2).

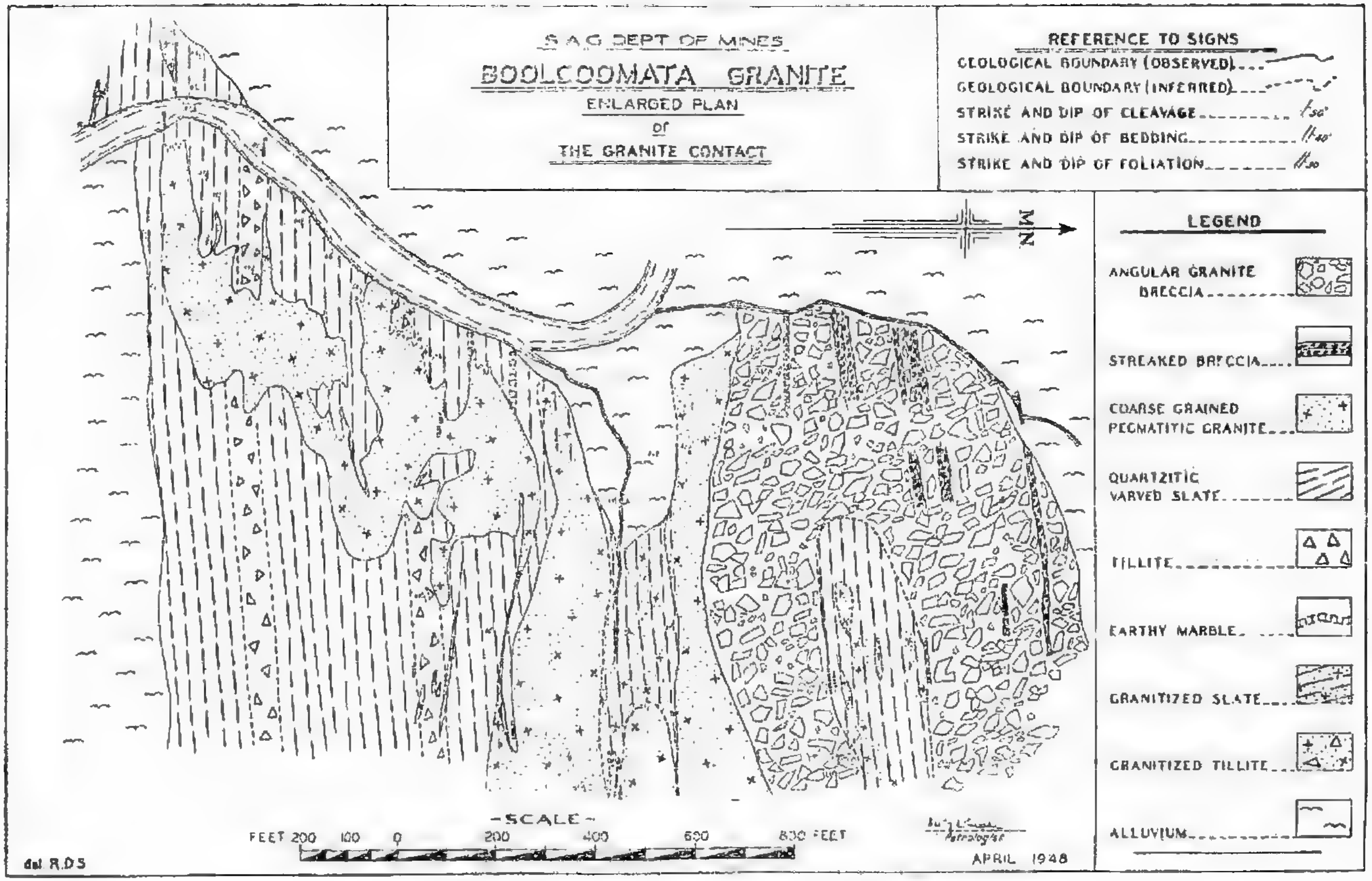
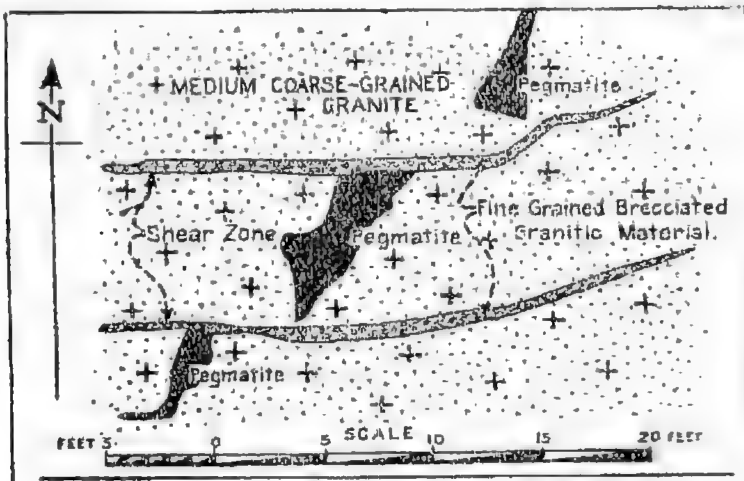


Fig. 3

Portion of the granite contact on an enlarged scale.

The main belt of breccia occurs along the southern border of the granite near the homestead and is more or less continuous for about a quarter of a mile northwards, while beyond this point separated discontinuous bands up to a hundred feet in width continue for a further half mile north. At either end these bands pass through fractured granite (fig. 2 and pl. xxi, fig. 1) into unbroken granite. The fractured granite is a stage in the formation of the breccia, and it is always closely associated with the brecciated granite. The drawings (fig. 1, 2) illustrate how the granite is thoroughly traversed by intersecting cracks which split it up into angular fragments. These cracks are at first quite narrow, but towards a zone of brecciation the fissures widen and become filled with finely crushed material, as the rock grades into the true breccia. The major mass of brecciated granite runs into alluvium near the homestead, while eastwards it is gradually obscured amongst the granite.

The breccia often carries tillite, slate and quartzite, which have not been granitized, forming local bands of angular boulders, set in a fine-grained chlorite-rich base running parallel with the general trend of the main granitic breccia.



PEGMATITE VEINS OFFSET BY NARROW SHEAR ZONES

Fig. 4

Pegmatitic veins offset by narrow shear zones.

The map (fig. 3) showing portion of the brecciated area on a scale of 100 feet to the inch, provides an indication of the general nature of the broken zone. The angular granite boulder breccia occupies the greater portion of the broken zone, while the general direction of the streaked and "bedded" portions is shown following the trend of the zone as a whole. An area of irregularly altered slate and tillite is shown with a doubtful boundary due to surface rubble obscuring the contact. Lens-shaped granite bodies occur in this rock.

Several lines of evidence support the concept of this peculiar formation as a breccia. The angular shape of the boulders and the nature of the matrix are typical of brecciation. Further, the angular fragments and the matrix materials are of the same type as the massive granite in the vicinity. The closely associated fractured granite represents partial brecciation.

The best evidence is that of shearing in the vicinity of the broken granite, where there are long narrow zones of mylonitized granite, two or three feet wide, in which the rock is reduced to an extremely fine-grained chlorite-rich

sheared mass, with flattened elongated remnants drawn out parallel to the fine banding in the crushed matrix. These shears, which are several hundred feet long, are parallel to the brecciated bands. Several of these are plotted on the map.

There are numerous examples of pegmatites, faulted by joint fissures, which are filled with fine-grained and angular granitic material (similar to the matrix of the main breccia) derived from shearing of the walls of the fissure by the movement which offset the pegmatites. These minor shear zones showing a displacement of a foot or so extend parallel to the trend of the breccia (fig. 4).

On the other hand, no evidence of displacement is visible in the country rock west of the point where the breccia runs out against the alluvial flat, while eastward the breccia disappears amongst the granite and can nowhere be traced. Thus, when its great width is taken into account, it is odd that, if this is really a breccia, it should have such a short longitudinal extent.

There are two other areas in which purely granitic rocks dominate; in both, however, there are patches of porphyritic felspar granite. Both have similar features and can be described under one heading. The grain size is irregular in these rocks, and biotite occurs as well as muscovite, thus it may perhaps be deduced that they are a little less completely granitized than the main granitic mass. Generally it is a medium-grained granite, but fine-grained or coarse-grained types occur in places. Although in the main massive, it sometimes becomes gneissic in greater or lesser degree, and may locally pass into injection gneiss or carry xenoliths oriented parallel to its gneissic structure. There is a special tendency for it to break down into numerous cuboidal blocks up to 6 feet in dimensions rather than to form massive granite tors like the main granite. This is probably due to a more closely spaced jointing system, and the more irregular grain size giving great unevenness during expansion. The granite boundaries are either well defined against the gneissic rocks, or grade by the addition of xenoliths into injection gneiss. Lath-shaped felspar phenocrysts up to ½" long and ¼" wide, oriented parallel to the direction of the gneissic structure, are common in these granites.

Toward the north-east these granites continue beyond the area mapped, while to the west they grade into gneissic rocks toward the border of the "batholith". There is no regularity in the distribution of the porphyritic phase in this granite, the strongest development being in the northerly belt of granite where porphyritic rock occupies a ridge for nearly a mile in an east-west direction. Irregular masses of pegmatite occur but are not strongly developed in either of these two regions.

III. THE AREAS OCCUPIED BY GNEISSIC ROCKS

These occupy a very large area. Throughout there is an abundance of granitic rocks ranging from fine- to coarse-grained types, which form, as it were, a base in which the gneissic material occurs. Thus, although the map shows large areas of these gneisses, these are not to be considered as made up wholly of this rock type, but rather that in these areas the occurrence of gneiss amongst the granites is the significant feature.

Pegmatites of an irregular nature, both large and small, occur in these areas.

It is usual for granitic and pegmatitic material to occur in lit-par-lit fashion along planes of schistosity in the gneiss, producing banded injection-gneiss. The bands of igneous rocks are closely spaced, varying in thickness up to an inch. Schistose or slaty rocks have been converted, in general, to dark biotite-muscovite-rich gneisses in which the black biotite bands contrast strongly with the light-coloured quartzo-felspathic ones.

Quartzites are not very much altered, although in places there is a partial loss of sedimentary banding, while elsewhere this is preserved by the introduction of granitic material along the bedding planes.

Calcareous rocks which have been included in the granitic and gneissic masses have a red-brown earthy appearance. They are massive, extremely fine-grained and show no alteration, unless their highly ferruginous nature is due to addition of iron oxides.

The distribution of the gneisses within the batholith may be seen on the map. There is a change toward migmatite well within the "batholith". This is poorly developed in the border zone and narrow belts of gneiss, but becomes important and at times dominant well within the batholith. Excellent examples of the gradation of injection gneiss to migmatite are common. The richly biotitic injection-gneiss gradually loses its dark bands, while the granitic bands expand and finally take up most of the rock, leaving only faint wisps of dark micaceous minerals winding in contorted lines through the granitic mass. Complete absorption of the sedimentary material is not common, for in most cases contorted, discontinuous faint wispy remnants remain. Where the gneiss was coarse-grained the final product is a coarse-grained granitic rock or migmatite.

The outcrops of gneiss are different from those of the granite. There are no "tor" structures or pavements formed by sheeting, but instead these rocks form low outcrops frequently running like blades or low rough walls for hundreds of yards, in parallel rows. Jointing is present only in the strongly granitic portions of the gneiss, thus it is not significant.

Large bodies of basic rock occur in the gneisses. The rock is a fine-grained uralitized dolerite carrying epidote, and often it is associated with quartz reefs. Similar associations of basic rock with quartz are also met with outside in the country rock. The larger basics are marked on the map, but smaller occurrences are numerous.

IV. THE COUNTRY ROCKS

There are three main types, *viz.*, slate, tillite and quartzite, and of these the slates have the greatest development. The tillites are distributed as one large formation, several smaller ones, and as minor intercalations in the slates. The quartzites occur similarly as one major band, and as groups of narrower bands. The former is, in the main, a thick massive quartzite with associated bedded quartzites, and it is interesting to note that quite large erratics are to be found in it in places. The several groups of thin quartzites are arkosic, presumably fluvioglacial horizons in the slaty and tillitic beds. Fracture cleavage occurs in the massive quartzites near fold axes, although in argillaceous quartzites there is a weak cleavage nearly always present. Jointing is strong in the massive quartzites.

The slates are strongly silicified and are of chocolate colour. In the main they are varved slates with alternate fine sandy and clayey bands numbering from 6-12 to the inch and in them cleavage is usually very well developed, but bedding is only obvious when the rock is weathered sufficiently to bring out the lithological differences. It is not always safe to use the varving as bedding because of its cross-bedded and irregular nature. Here and there the slates carry isolated erratics up to 10″ in dimensions. Frequently the slates are without structure, even cleavage disappears, when they resemble dark black-brown hornfels. Occasional intercalated earthy limestones occur in the slates which are discontinuous along the strike and are of no use as markers. Near the fluvioglacial sandstones

the slates change by enlargement of the sandy component of the varving, and pass into arkoses. These arkosic horizons are made up of several bands of quartzitic rock up to 50 feet thick, separated by slate beds of similar widths.

The major tillitic horizon will be considered later, while the other tillitic beds are insignificant and may be passed over. There is the usual assortment of rock types as erratics, although granitic, gneissic, and pegmatite material dominates. Boulders range from small ones an inch or two in size to larger ones measuring a foot or more in diameter. The base of this tillite is slaty or phyllitic, rich in micaceous and chloritic material with a well-developed cleavage.

V. STRUCTURE

(a) Within the Batholith

The structure is straightforward, and although locally confused, these small areas may be ignored in considering the general features.

The folded map shows the regularity of the strike of the foliation in the gneisses, and in the granites, when present. The dips are steep to vertical with a tendency to slope slightly southward towards the contact.

There is a tendency for one direction of jointing to follow the foliation, and for one or two others to develop as nearly as possible at right angles to it.

(b) In the Country Rocks

Great difficulty occurred in deciphering structures in those areas where alteration and injection by pegmatites occurred at a maximum.

In the southern and western portion of the area mapping was simple, but elsewhere there is so much alteration with the production of gneiss that bedding is obscured or even obliterated. The best marker beds available were plotted, thus a general idea of the structure was obtained, but there are many local disturbances and discontinuities.

On the edge of the altered area a syncline occurs with steeply-dipping overturned limbs to the south, becoming normal with flatter dips to the north. Beds in the northern limb of this fold are strongly gneissic and carry numerous pegmatites, while the southern limb is made up of normal quartzitic and slaty rocks. Air photos suggest the continuity of this synclinal axis eastward beyond the area mapped.

North of this syncline an irregular, indefinite anticline occurs. Bedding is obscure and indefinite here, but there is a general suggestion of an anticlinal structure. Pegmatitic injection accompanied by intense ptygmatic folding is at its greatest development in this region, and it is possible that these beds were converted to a semi-plastic state during the folding, hence their unusually irregular nature (pl. xxi, fig. 2, 3). The truncation of beds and their disappearance into masses of pegmatitic injection gneiss is a common feature. Air photos indicate the presence of a fold axis extending eastward as a continuation of the anticlinal axis through these altered rocks.

The greatest density of pegmatites, the abundance of injection-gneiss and the irregular discontinuous structural features of the rocks, suggest, if one favours a granitization theory of origin, that the country in this vicinity is in an advanced stage of conversion to granitic rock, and the area is thus comparable to the belts of gneissic rock within the batholith. If this is true, then in this locality the "granitic front" is moving in along an anticlinal axis.

VI. METAMORPHISM

The study of metamorphic stages is difficult because in the places where change has occurred there is a great amount of pegmatite which would be expected to introduce complications due to introduction of material with great effects on the already stressed country rock.

On the western side of the area where folding is absent the sediments are normal varved slates with occasional interbedded quartzites. Towards the east, the alteration of the slates becomes progressively greater, thus half a mile west of the homestead the slates become garnetiferous muscovite-quartz schist, while interbedded quartzites develop epidote, actinolite and occasional red almandine garnets.

Amongst the injection-gneisses in the greatly altered country a mile south-east of the homestead there are gneisses free, or nearly so, of felspar. They differ from the injection-gneiss by the absence of thin quartzo-felspathic banding and may therefore be considered as products of stress rather than injection and as representative of local advanced regional metamorphism. High-grade knotted crystalline schists are associated with these gneisses. The more arenaceous beds associated with these occur as quartz mica-gneisses with epidote. These beds in the lesser metamorphosed areas are quartz-mica-schists rather than the more common mica-schists which were varved slates.

Pure quartzites amongst the greatly altered rocks are converted to epidote-rich formations, in which bands up to 12″ wide, rich in green epidote, traverse the rock parallel to the bedding. Occasionally epidote bands traverse the rock at an angle to its bedding, filling joint-fissures, thus suggesting introduction of epidote-forming material from an outside source. The presence of a little graphitic mica-schist is noted on the map showing mineral occurrences. This has a gritty quartzitic base, with argillaceous and graphitic material making up the major portion of the rock.

Muscovite kyanite-schist occurs with kyanite up to an inch long, but it is restricted to certain horizons. The kyanite crystals are arranged parallel to the schistosity and their presence indicates an advanced stage in the metamorphism. Some of the high-grade knotted mica-schists contain small black prisms of tourmaline forming a brownish red mica-tourmaline knotted schist. Although garnets occur in the mica schists they are not found in the gneissic rocks.

Lime silicates, such as sphene, zoisite and epidote, occur in the schists and gneisses. Thin impure siliceous limestones frequently occur amongst the varved slates and arkosic quartzites, thus it is not surprising to find these minerals developed in relatively large quantity in favourable places. Incipient growths of sillimanite occur in some of the gneisses.

VII. IGNEOUS INJECTION IN COUNTRY ROCK

Pegmatitic and Granitic Phases

Pegmatites are extremely plentiful, while there are a few small granite bodies, particularly west of the homestead.

Granite bodies are situated mostly close to the contact of the batholith with the country rock, none occurring beyond half a mile south of it. Closer to the homestead granites are associated with milky quartz reefs. Coarse pegmatitic granite occurs on the ridge adjacent to the homestead. This body has irregular borders and penetrates along the schistosity of the country rock in separated tongues, and it can be traced without interruption back into the granite of the bathlolith. Thus at this point the batholithic contact is sharp and very irregular in shape (see fig. 3).

The pegmatites are best developed outside the zone of granitic injection. There is a great density of pegmatite in the anticline south-east of the homestead, while away from this region they thin out, and on the western side of the map disappear altogether. They are mainly sill-like, but occasionally are cross-cutting. Most of the pegmatites are enormous in outcrop, standing up like great walls and extending considerable distances. Generally they bear black tourmaline crystals, either small with scattered distribution or as nests of radiating lustrous black prisms, producing masses of schorl rock. Pegmatites, too small to map, are extremely numerous among the larger instrusives, while in lit-par-fashion, pegmatitic material makes the injection gneisses which are the main rock type of this area. Most of the pegmatitic intrusives are in argillaceous rock while there is a noticeable increase in pegmatites where quartzites occur. The pegmatite is very coarse-grained and rich in felspar for which mineral it has been worked (see fig. 5), while in one or two places beryl crystals up to 18 inches long occur. Here, too, there is usually an abundance of black tourmaline and muscovite. The latter, although often in great quantity, is unfortunately in nests and pipes made up of radiating and thickly inter-grown bundles of small plates, which on the average are only a few inches long. Nowhere in the area, despite the abundance of pegmatites rich in mica, are there any occurrences bearing large marketable plates of mica. The beryl is not worked except in cases where felspar is being obtained, when the beryl is separated out and sold when a sufficient quantity has accumulated. White to light-pink medium-grained aplites carrying little else besides quartz and felspar are sometimes associated with pegmatites.

Basic rocks are mainly confined to the pegmatite-bearing areas, while a little occurs near the contact as well as several large and smaller basic masses within the granite mass itself.

The largest basic intrusive occurs near the Woman-in-White Copper Mine, in the nature of a fine-grained uralitized and epidotized dolerite. It is associated with both pegmatite and quartz reef and carries bundles of large blades of amphibole (a dark green actinolite). Here the basics occur among altered quartzites, rich in felspar and biotite bearing copper minerals which have probably been introduced by the basic rock. The copper is in the form of the carbonates, malachite and azurite.

An interesting group of brownish crystalline rocks occurs about three-quarters of a mile south of the homestead. These are peculiar albite-rich rocks of igneous character, traversing the country rock in a north-westerly direction. There are probably several dykes in this group, each being several hundred feet long and up to 30 feet wide.

Quartz reefs, often of large size, are to be found where there are bodies of pegmatite and granite. All are quite barren of minerals, and vary from milky white quartz to a semi-clear smoky type. In places there is an interesting variation in the quartz, resulting from the presence of a little pink felspar, suggesting a primary origin of these particular reefs. They are best developed on the western extremity of the pegmatite area in schists interspersed with, and parallel to, the pegmatites, thus they may have been formed late in the period of pegmatitic injection.

Silicification of country rock in places round the contact has resulted in the production of fine-banded dense quartzitic rocks which are very hard and have a flinty fracture. In most cases this has been effective only a few chains along the strike. Mylonites which occur here and there around the contact are similar in appearance, but in the silicified sediments the banding is a continuous, original,

sedimentary feature, whereas in the mylonite the discontinuous and flattened lens-like bands are obvious signs of crushing. Blasto-porphyritic remnants also occur in the mylonites.

VIII. MINERALIZATION CENTRES

The occurrence of the various minerals is shown in fig. 5. These are outside the granitic area, except for two localities which are noted because of shafts which have been sunk there. The materials in the dumps contain no metalliferous mineral, but according to local information they were sunk for gold and copper. Much more definite are those occurrences in the country rock, where evidence of mineral occurrence may be seen in outcrops or in the dumps.

The most important mineral is *barytes*. A great mass of it occurs along the ridge at Mulga Hill, as an impure barytes lode with a bedded structure preserved from the quartzite it has replaced. The extremities of the ore body become siliceous and gradually pass into bedded quartzite. The barytes is very impure and stained red and green with copper and iron compounds, and in addition it carries grains of ilmenite and haematite up to $\frac{1}{2}''$ in dimensions. Further north, barytes occurs amongst schistose rocks as smaller discontinuous bodies of better quality, and although it is iron-stained, granular iron ores are absent. Costeans across the schists reveal seams several feet wide but their continuity in depth is unknown.

Felspar is of importance in this area and great quantities of it occur which could be readily worked. Near Mulga Hill is a large felspar-rich pegmatite from which much felspar has been quarried. Muscovite, tourmaline and beryl are also abundant in this pegmatite.

Copper occurs in several places. Near the Woman-in-White Quartz Reef, there is a shaft now full of saturated copper sulphate solution with crystals of copper sulphate encrusting the walls of the opening above water level. The country rock is quartzite, carrying small strings and veins of azurite and malachite. Over the hill to the north there are a number of shafts sunk in quartzites and slates which carry copper carbonates in their outcrops, but apparently nothing of any value was obtained. These shafts, it is said, also yielded some gold.

Graphite occurs in one locality. It is of poor grade and occurs as a gritty graphitic mica schist.

Other well-developed minerals, of lesser economic importance, include the following:—

Garnet, a red almandine variety, occurs associated with epidote and actinolite in bunches of large crystals in quartzite beds on the hill south of the homestead.

Sphene, epidote and zoisite are found on this same hill and elsewhere in in the area. Thin impure calcareous beds amongst schistose and slaty rocks probably supplied the lime to form these minerals.

Kyanite occurs as thin bluish blades in schists to the west of Mulga Hill.

IX. FEATURES OF THE CONTACT

The contact of the igneous rocks with the country rocks is not always visible, being in part covered by alluvium.

To the west the contact is sensibly straight, very sharp against the gneissic granites, and trends north-westerly (pl. xx, fig. 4). The varved slates scarcely change right up to the contact, except for the last two or three feet where they lose their identity and become greyish, schistose or phyllitic, and develop large

Fig. 5
The principal mineral occurrences of the area.

micas. Similarly, calcareous and tillitic bands are without change right up to the contact. Although the line of contact between the country and the granite rock may be mapped as a regular line, it has embayments and other irregularities extending either side of a mean contact line, but they cannot be shown on the scale used. An unusually irregular portion of the contact is illustrated in fig. 3. The contact to the north-east is well defined with strong mylonite zones developed along it. The country rock against the most easterly portion of the contact shows an enrichment in felspar, producing a grey-white fine-grained granular rock.

X. GRANITIZATION PHENOMENA

Evidence to support a granitization theory of origin is to be gathered from (1) the major folded tillite horizon in the south, and (2) from the batholith itself.

The tillite forms excellent exposures where it is folded in the southern portion of the area. The rock, where well granitized, has a dense matrix of pink orthoclase, black biotite, muscovite and quartz, in which erratics with indistinct outlines are set (pl. xx, fig. 3). This matrix was formerly the normal phyllitic or slaty type which is typical of tillites in this country. The stage of alteration of the rock is evidenced by its erratics, the outlines of which become faint in strongly granitized rock, while the original shape and lithological character are retained in unaltered portions of the tillite still retaining a slaty base. Argillaceous erratics are dark and hornfelsic, with none of the original slaty cleavage. Quartzite erratics are unchanged except for re-crystallization which has occurred in some, producing a dense structure which is so continuous that individual grains cannot be distinguished.

Granitic boulders appear fresh and unaltered, probably due to recrystallization with the reconversion of secondary minerals to the original primary ones, which would readily occur under granitizing conditions. Gneissic rocks appear fresh and recrystallized with a strong gneissic structure, which may be the result of recrystallization of components such as felspars, quartz, and micas, to larger individuals.

The granitic nature of the rock as a whole is manifest by its general appearance in outcrop, namely, in the development of right-angular joint sets, and sheet jointing parallel to the surfaces. The granitization is not homogeneous throughout, for unaltered tillite may be in contact with strongly or partially altered material. Where granitization has been weak the tillite retains its slaty-phyllitic base, its grey colour, and its typical form of bladed cleaved outcrops. These weather relatively easily so that erratics lie scattered about, and cavernous holes, the spaces once occupied by erratics, appear in the outcrops. This contrasts strongly with adjacent rounded granitic-looking outcrops with no loosened and weathered erratics lying about. The solidity of the altered tillite is exhibited where, in the anticlinal fold, it forms a great ridge covered with rounded platy outcrops and granitic tors. Bands of fluvioglacials within the tillite take on an aplitic appearance where the granitizing effects are greatest. When weathered extensively, the granitized tillite looks like any decayed granite. The rectangular joints become enlarged and the rock becomes swollen and friable by internal expansion of felspars as these alter to clays, finally leaving a sandy micaceous residue of soil surrounding the outcrops.

North-westward from the main anticline in tillite, a long ridge of altered tillite makes a strong topographical feature. Irregularly granitized tillite and fluvio-glacials extend the full length of the ridge, but toward the creek at the north-west end of the ridge only odd bands of well granitized rock remain amongst unaffected tillites, fluvioglacials and varved slates.

A few hundred yards to the north of the granitized tillite there is a small patch of granitized country rock. Locally the structure of the varved slates becomes unrecognisable, but in general they appear to "flow around" this small altered area. Various rock types occur within, including an abundance of injection-gneiss with granites and pegmatites. Quartzites, having well-defined outcrops, wind about amongst the latter and do not appear to have been much altered. Some amphibolite occurs here also, while on the north-west margin there is a great development of small quartz reefs.

Whether the "batholith" itself has resulted from intrusion or granitization is difficult to decide without more information, particularly chemical data regarding the composition of the various zones of rock types.

The zones of injection gneiss carry a great deal of granitic and pegmatitic material and often this material actually dominates over gneissic rocks, while the gneissic rocks themselves are largely made up of quartzo-felspathic "lit-par-lit bands". Well within the batholith these injection gneisses are gradually replaced by migmatites, indicating a conversion of the material of these gneisses to the components of granite. This conversion merely requires a recrystallization and rearrangement of materials already present in the gneisses, attended by the expulsion of magnesium and iron. The main constituents of these gneisses are quartz and micas or quartz-felspars and micas, while the granites in the area have similar composition with little or no biotite. Thus it would appear that MgO and FeO have been eliminated during the conversion of the gneiss to granite and that some felspar has been added. The gneisses also carry a good deal of iron ore as disseminated grains, and since these do not occur in the granite they also must have been eliminated during the conversion.

Larger and smaller bodies of basic igneous rock within the "batholith" are situated in the zones of gneiss and may represent local concentration of cafemic constituents driven from country which has been completely granitized. Similarly, basics in the country rock are confined to the areas where there is an abundance of pegmatitic and granitic material which have produced high-grade schist, gneiss and injection-gneiss, thus these, too, may be basic segregations rather than intrusives. In many cases they form irregularly-shaped bodies which are not truly dyke or sill-like.

The structure of the gneisses suggests replacement rather than intrusion. There is a general undisturbed schistosity throughout the "batholith" sensibly parallel to that of the adjacent country rock close to the margin of the granite.

Within the batholith there is evidence of two stages of the complete granitization process.

The areas rich in injection gneiss may represent the preliminary desilication stage brought about by felspathization, plus some degree of basification. The greater part of these gneisses are felspar-rich because of numerous thin granitic bands within them, the introduced felspars being mainly microcline, perthite and oligoclase. This indicates a considerable enrichment in the alkalies potash and soda, *i.e.*, a desilication of pre-existent country rock. Furthermore, these gneisses are often rich in biotite and muscovite which represents an increase in K_2O, MgO and FeO, for there is insufficient of these bases in the country rock to permit the direct production of these minerals in the gneisses without outside augmentation. These added constituents may have been eliminated from country already completely granitized, i.e., from country now occupied by granite or porphyritic granite and may be regarded as temporarily concentrated in the gneisses (which are country rocks in the preliminary desilication stages). The next step would therefore be the elimination of the MgO, FeO and excess K_2O from the

gneisses into the surrounding country rock and the conversion of the gneisses into granitic-looking rocks. Apatite (representing P_2O_5), magnetite, and other iron ores (representing FeO) are relatively abundant in the gneisses and may represent some added degree of basification.

There is a similarity between the irregular granitization within the "batholith" and the granitized tillite further south in which are found all gradations from completely unaltered tillite to crystalline granitic material in which the original erratics are scarcely discernible. Hence it would appear that granitization as a whole and the preliminary desilication process has operated selectively in favourable places and on favourable rock, thus explaining why the tillite (as a whole) is granitized while beds above and below are not.

The possible existence of "Fronts"

Outside the batholith there is further evidence of granitization afforded by concentrations of certain materials as minerals in country rock adjacent to the batholith.

On the hill opposite the homestead, sphene, garnet, hornblende and epidote are abundant and may represent FeO, MgO, TiO_2 expelled from the batholithic area, while the occurrence of the albite magnetite rocks nearby suggests local concentration of migrating Na_2O and FeO. The quartzites have locally been altered to quartz-biotite-epidote-gneisses and, considering the large quantity of epidote present in them as well as the abundance of biotite, some MgO and FeO must have been introduced into these rocks from an outside source, *viz.*, from country which has been converted to granite.

The occurrence of copper and iron adjacent to the batholith may also be significant, having been driven forth from the granitized area and accumulated in these places. The barytes which occurs close by may have resulted from the deposition in favourable places of minor disseminated quantities of barium compounds expelled from the granitized sediments. The schists, gneisses and quartzites in which these minerals occur are in advanced stages of felspathization, manifest by numerous felspar-rich pegmatites amongst them and the abundance of felspar and biotite in the gneisses themselves.

Hence it would appear that in the eastern portion of the area where the country rock is strongly folded and thoroughly permeated by pegmatites, and where the greatest variety of minerals bearing basic constituents are concentrated, that a new centre of granitization is being established outside the batholith, producing rocks comparable to those of the gneissic belts within the batholith.

XI. CONCLUSIONS

There is much evidence which suggests that the granite masses of Bookcoomata are the result of a process of granitization rather than of intrusion. Similarly the alteration of the bordering country rocks may not be entirely due to straight-out processes of regional metamorphism, but may be partly or even wholly due to metasomatising effects of emanations driven forth from an adjacent area undergoing changes which eventually converted it to granitic rock.

However, before indisputable conclusions can be reached on these problems, more detailed work must be done. This particularly includes chemical work, in order to be able more accurately to state the relative gains and losses of substances in the several areas. Such conclusions as have been reached here by field observations and by the examination of thin sections, can be only regarded as tentative, otherwise false impressions may be gained.

It is hoped that they will be a useful guide to those who will probe more deeply into the origin of this granite mass and its possible relationship to the widespread mineral occurrences in the Olary district.

ACKNOWLEDGMENTS

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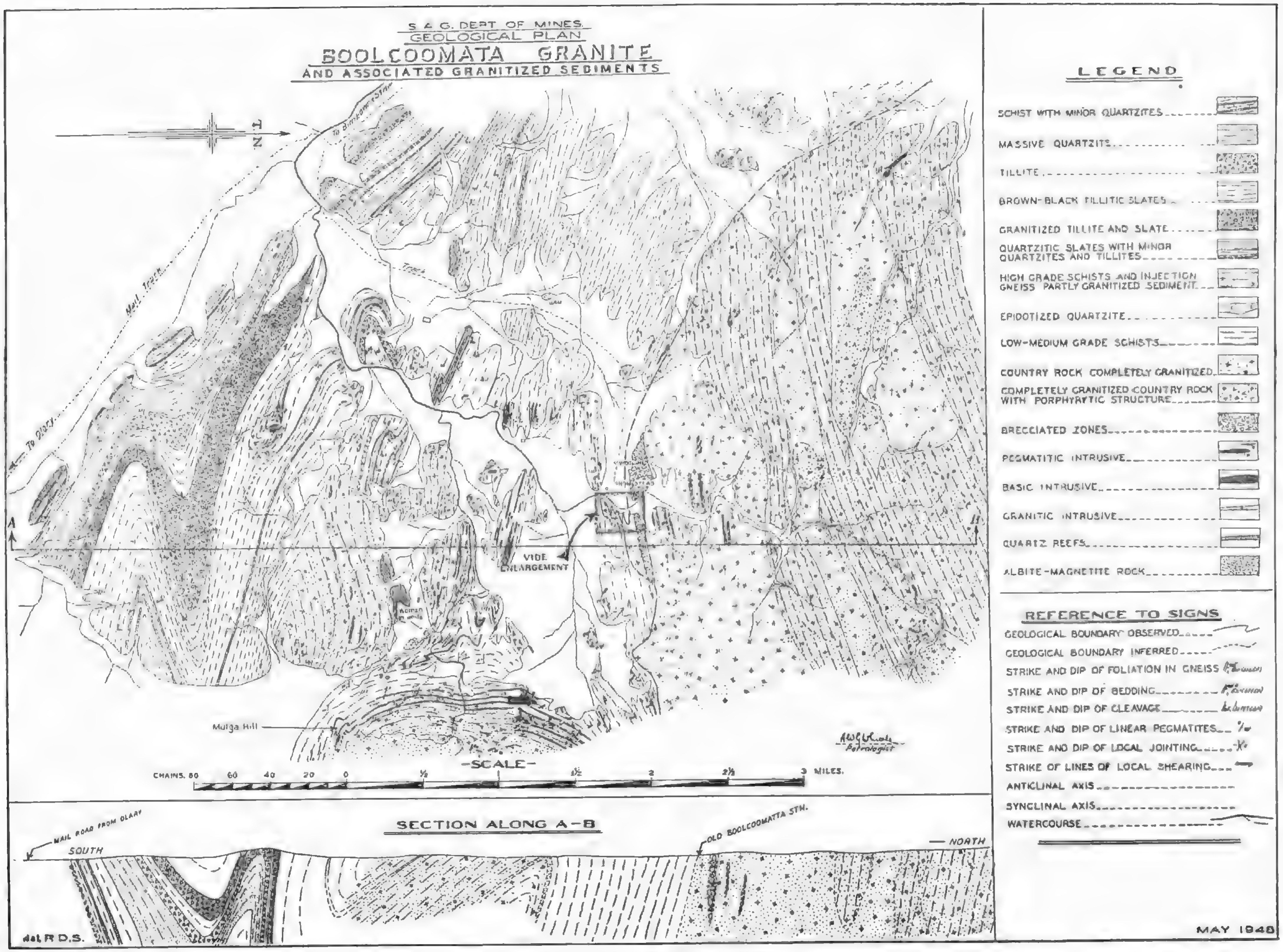

GEOLOGICAL MAP OF AREA

Fig. 1

Rock pavement near the Homestead, exhibiting the structure of the granite breccia.

Fig. 2

"Pseudo bedding" in brecciated granite. The included fragments are rounded granite or felspar fragments several inches in size arranged in parallel rows.

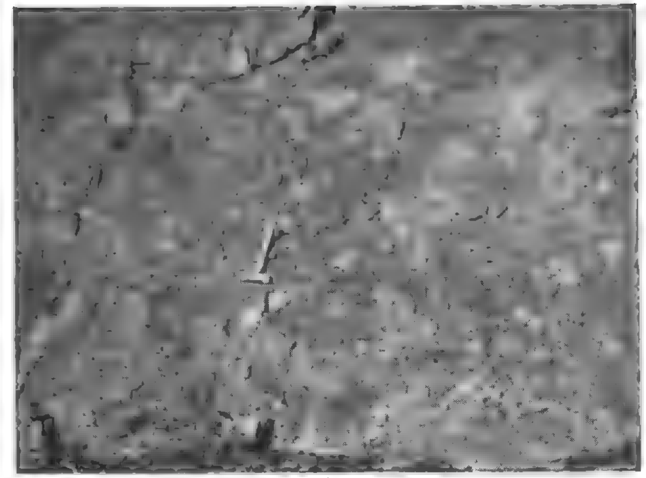

Fig. 3

Granitized tillite, in which the erratics may be seen only with difficulty because of their indistinct outlines. The rock matrix is granitic in nature.

Fig. 4

The granite contact. Light-coloured gneissic granite occupies the background with dark quartzitic and tillitic slate in the foreground. The contact is quite sharp in this locality.

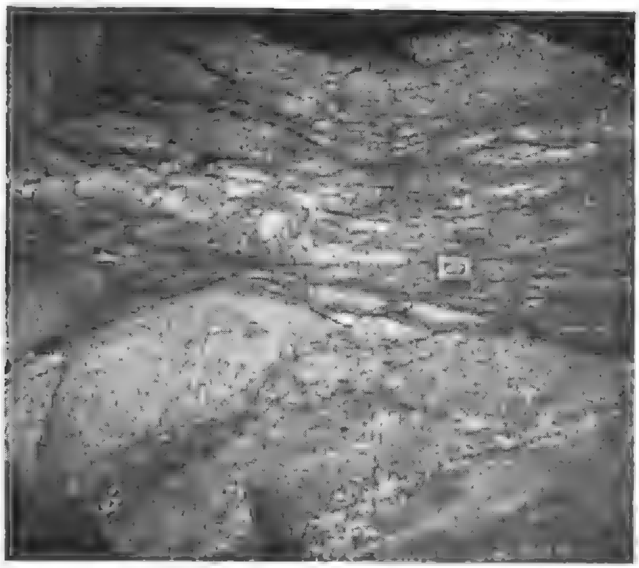

Fig. 1

Fracturing in granite bordering the brecciated granite. The fractures are filled with richly chloritic and biotitic pulverised granite.

Fig. 2

Ptygmatic folding exhibited by thin pegmatites in high-grade schists.

Fig. 3

Complex ptygmatic folding of thin pegmatites in high-grade schist and gneiss.

STURTIAN TILLITE OF MOUNT JACOB AND MOUNT WARREN HASTINGS NORTH FLINDERS RANGES

By D. Mawson

Summary

Since my earlier contribution (Mawson, 1934) on the general geology of this area, the broader features of the Proterozoic stratigraphy of the Flinders Ranges have been solved by a succession of reconnaissances extending over wide areas during the past twelve years. What were then referred to as the "Munyallina beds", I hae since been ablt to correlate satisfactorily with defined horizons in the Proterozoic succession of the Adelaide System. As a consequence, this paper is being written with that object in view as well as to supply, as a result of a further examination of the region executed in the year 1939, a detailed cross-section through the glacigene beds.

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[Read 11 November 1948]

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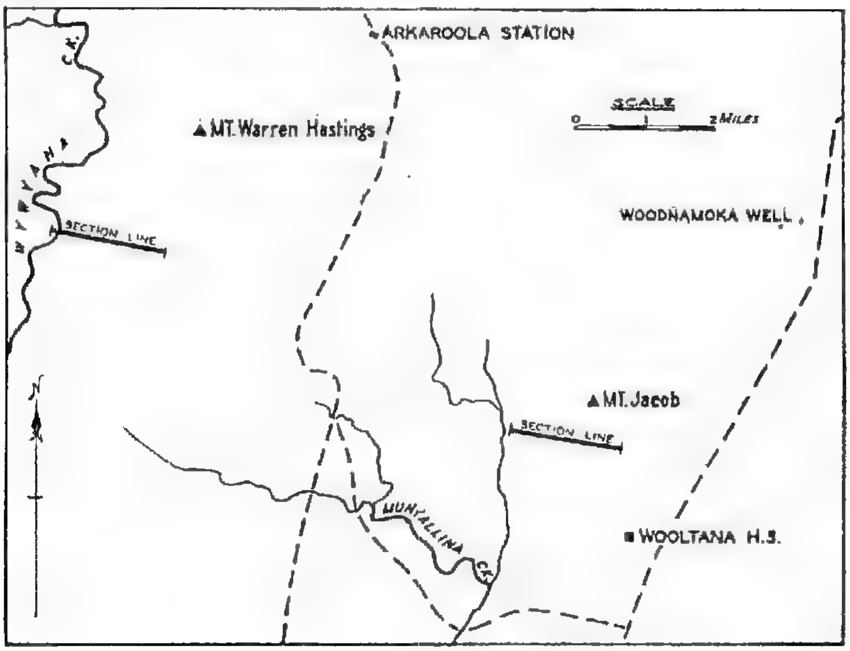

Fig. 1

A very important matter left in doubt when my earlier contribution was published was the existence or otherwise of a fault along the face of the massive Cave Limestone formation. The possibility of a major fault in that location was

* Geology Department, University of Adelaide.

discussed (Mawson, 1934, 188) but finally discounted. However, our later investigation, and stratigraphical considerations, show this to be a major fault line, throwing down some thousands of feet the block to the east thereof; namely, the country between the Cave Limestone belt and Mount Jacob. Thus it is now demonstrated that the glacigene beds of the Mount Jacob Range are repeated by faulting at Mount Warren Hastings.

Detailed cross-sections of the beds in these two localities are graphically displayed in fig. 2 herewith. The lines of section are marked on the locality map, fig. 1.

CROSS-SECTION OF THE GLACIGENE SEDIMENTS OF MOUNT JACOB

The mail coach track from Wooltana homestead to Paralana follows north, for the first four miles, along the foot of the Mount Jacob Range, with the gently falling Lake Frome Plains extending beyond the horizon to the east. From this track, at a point about two miles north of Wooltana homestead, the geological section to be detailed below was run to the west over the Mount Jacob Range, traversing the complete thickness of the glacigene beds. These are clearly Sturtian in age. Herewith are descriptive notes dealing with each of the divisions recognised in the plotted cross-section (fig. 2), stated in ascending order from below upwards.

1. A few hundred yards across the outcrop of poorly exposed pre-glacial sediments, amongst which slates and dolomites are conspicuous. Minor intrusive bodies of diabase have been reported (Mawson, 1926).
2. A belt of melaphyre, in places amygdaloidal. This may have been a lava flow in Proterozoic times.
3. The above melaphyre is overlain by a reddish sandstone, of some considerable thickness, dipping moderately steeply to the west. It apparently post-dates the melaphyre. In several places it is greatly disturbed and shattered, suggesting that it is traversed by fault lines (Late Tertiary) connected with the downthrow of the Lake Frome Plains to the east. Dip variable 30° to 50° to W; strike N. 2° E.
4. Melaphyre with some intercalations of a consolidated tuffaceous nature form the lower face of the range. The relation of the red sandstone to this basalt was not satisfactorily determined, the locality being disturbed by faulting. However, westward from that point, the succession of beds is undisturbed by faulting.

   This thick basaltic formation appears to be mainly in the nature of a lava flow and was originally scoriaceous in part, more especially at the upper and lower limits. Former steamholes are now filled by secondarily introduced minerals, resulting in some locations of a truly perfect and striking example of an amygdaloidal melaphyre. The total thickness of this basaltic formation was found to be 590 feet. Its upper surface is irregular and had evidently been subjected in places to some erosion prior to deposition upon it of the overlying glacigene sediments.
5. Dark grey to greenish-grey breccia. Near the base there are plentiful angular pieces and boulders of the underlying basalt, also abundant fragments of limestone and dolomite, and some shale, quartzite and reef quartz. This is now interpreted as a glacigene breccia. At about 300 feet above the base some bands exhibit evidence of water

True thickness in feet

sorting. Above this level the tillite is of a more sandy nature; in other ways also there is indicated to some degree the effects of water sorting and elutriation. Erratics up to 2 feet in diameter were observed. In the upper part of this division, limestone erratics are scarce; of these quartzite is common, basaltic rocks are plentiful, and occasional erratics of quartz porphyry were noted	500
6. Tillite with much fine base in which are distributed erratic boulders up to 18 inches in diameter. Jasperoid quartzite is the more abundant rock type represented among the erratics. Only a small percentage of the erratics show faceting; striae are rarely seen. A well striated example was observed partly embedded in the tillite at about 200 feet above the base of this division. At about 300 yards above the base there are some narrow glacio-fluvial sand bands intercalated in this tillite. At higher horizons, erratics exhibiting striations are more frequent. These erratics are still mainly quartzite, some of a white variety, others the jasperoid type. Erratics of quartz porphyry, considerably kaolinized, are less frequent	525
7. Glacio-fluvial sediments alternating with tillite. (a) Band of sandstone, 1 ft. in thickness. (b) Above is tillite, 6 ft. thick. (c) Band of sandstone, 1 ft. thick. (d) Tillite, 3½ ft. thick. (e) Sandstone in part exhibiting ¼-inch laminations. At the base is a section of true varves; alternating laminae of red argillite and white sand. Thickness, 93 ft. Dip, 33° to W.; strike, N. 5° E.....	105
8. Typical tillite in which some erratics of an unusual red-coloured porphyry were observed	110
9. Commences below as a sandy phase of tillite but passes upward into a normal tillite in which small erratics are studded through an abundant rock-flour base	100
10. Glacio-fluvial, gritty sand-rock with some pebble erratics	15
11. Commences below as characteristic tillite but quickly changes above to a sandy phase. Near top are abundant pebbles in a very sandy base	100
12. Glacio-fluvial sandstone 2 feet thick below, followed by 10 feet of sandy tillite, capped by 20 feet of glacio-fluvial sandstone	32
13. Somewhat sandy tillite with plentiful erratics	200
14. Sandy tillite, less resistant to weathering	60
15. Characteristic tillite in which, towards the upper limit, along the summit of the Range, there are exceptionally large erratics up to 6 ft. in diameter; most of these are of quartzite, and many are well striated	365
16. Tillite with plentiful large erratics	360
17. Characteristic tillite with many large erratics exhibiting striated faces. An unusually good example of an ancient, typical tillite. Among the largest erratics are chocolate-coloured quartz-feldspar porphyry and quartzite, one of the latter measuring 5 ft. by 5 ft. by 4 ft. This is the topmost of the glacigene beds and where erosion has stripped the	

True thickness in feet

overlying beds there is exposed the original surface of the old tillite formation. Thus can be observed on the old surface a concentration of erratics standing in relief by removal of the finer-grained elements of the old boulder clay, evidently the result of surface wash. See pl. xxiii, fig. 2 75

Total glacigene formation 2,547

18. Immediately above the tillite is glacio-lacustrine mud and an irregular band of limestone up to 3 ft. in thickness, followed by blue-grey shales, dipping 23° to the west. Strike N. 8° E. (see pl. xxiii, fig. 1). These post-glacial shales are, in part, finely laminated and correspond to the Tapley Hill shales of the Sturt locality near Adelaide. As they pass upwards, bands obviously somewhat calcareous make their appearance, and finally, at about 1,200 feet stratigraphically above the base, a thick limestone formation with some cryptozoonic mottling is met with.

The general upward succession of strata to the west of the Mount Jacob Range tillite figured in the diagram herewith (fig. 2) and extending as far as the vicinity of the Cave Limestone is well set out in the section on page 190 of my earlier reconnaissance (Mawson 1934). Note, however, that a fault extends in a general north to south direction along the Cave Limestone belt throwing down the Mount Jacob range block.

THE MOUNT WARREN HASTINGS BELT OF GLACIGENE BEDS

This belt is a repetition by faulting of the Mount Jacob tillite. Some variation in details of the succession and in total thickness is to be noted, but this may be expected as anticipated irregularities inherent in glacial sediments deposited at points several miles apart.

A matter calling for special remark is the fact that whereas these glacial depositions at Mount Jacob rest upon basaltic effusive debris, there is an absence of such at the western outcrop, the glacial beds there lying directly on top of the undisturbed dolomite-magnesite-bearing series. This line of section is marked on the locality map, fig. 1.

Notes relating to the numbered divisions appearing on the diagrammatic cross-section (fig. 2) are given below.

True thickness in feet

1. Preglacial shales and dolomites with some bands of sedimentary magnesite. These beds strike N. 12° E. and dip to the west, ranging between 28° and 34° (see pl. xxii, fig. 1).
2. Tillite with abundant dolomite erratics. Quartzite erratics up to 3 feet diameter are also abundant and not infrequently show glacial striae. A fine-grained grey granite is also represented among the erratics (see pl. xxii, fig. 2) 50
3. Glacio-fluvial sandstone, siltstone and rock-flour beds with some erratics. Included are occasional bands a foot or two in thickness of typical tillite 626
4. Typical tillite at base of this section with quartzite erratics up to 2½ feet long; some large ones of grey granite and gneiss. At 50 feet above the base the tillite becomes more sandy until finally a glacio-fluvial arkose; later, approaching the top of this division, it reverts in nature to a sandy tillite 244

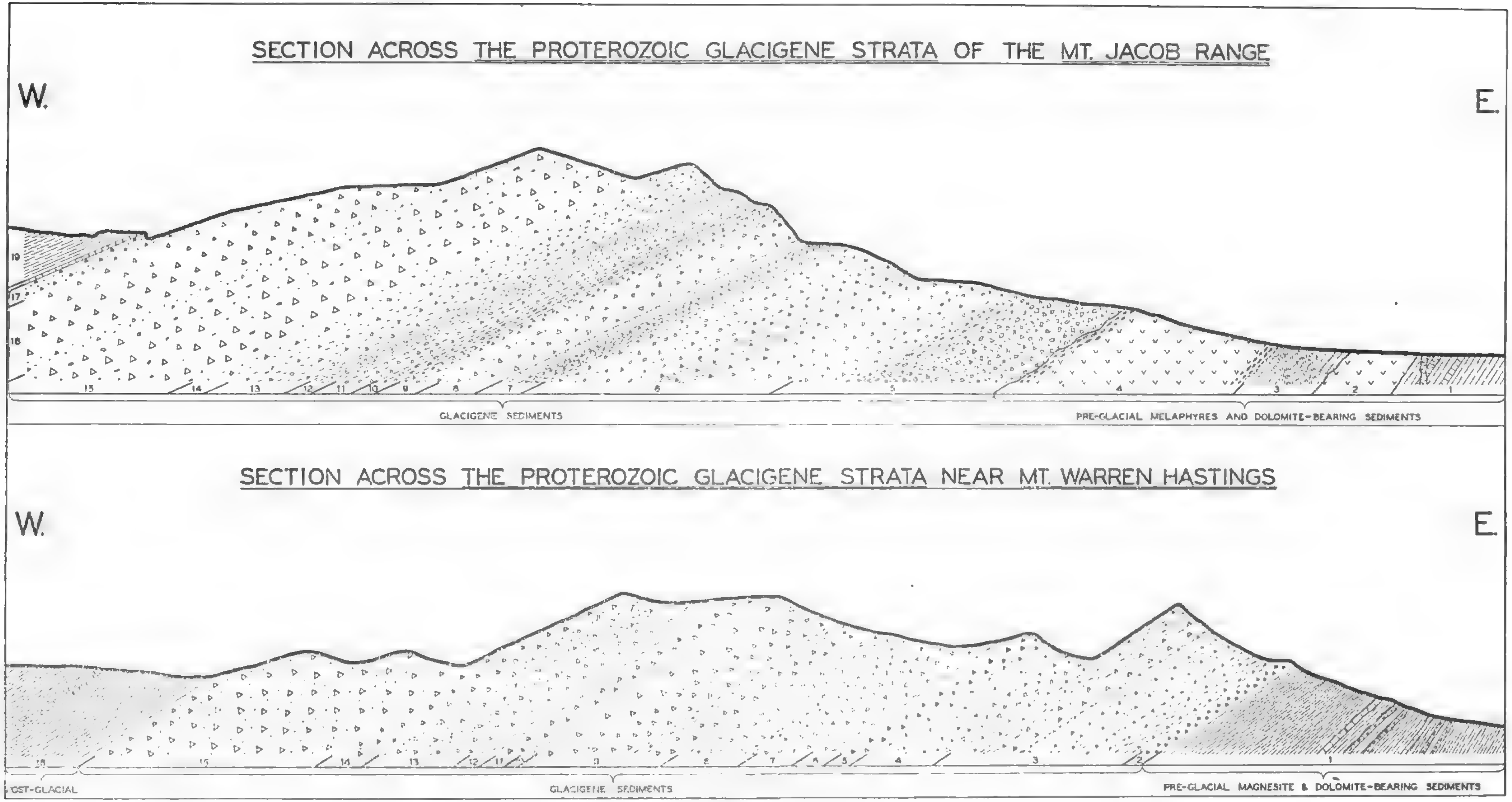
SECTION ACROSS THE PROTEROZOIC GLACIGENE STRATA OF THE MT. JACOB RANGE
W.
E.
GLACIGENE SEDIMENTS
PRE-GLACIAL MELAPHYRES AND DOLOMITE-BEARING SEDIMENTS
SECTION ACROSS THE PROTEROZOIC GLACIGENE STRATA NEAR MT. WARREN HASTINGS
W.
E.
POST-GLACIAL
GLACIGENE SEDIMENTS
PRE-GLACIAL MAGNESITE & DOLOMITE-BEARING SEDIMENTS

Fig. 2

		True thickness in feet
5.	Tillite with well glaciated erratics	64
6.	Glacio-fluvial silts and muds, containing large erratics in the upper section	84
7.	A glacial mud base with plentiful very large erratics up to 5 feet diameter. Nearly all erratics are quartzite; one is a quartzite conglomerate (pebbles in it also quartzite)	146
8.	Tillite and glacio-lacustrine mud shales with plentiful large erratics; one is a coarse granite	218
9.	Typical tillite with abundant striated erratics to 3 feet in diameter; granite with quartzite common. Some erratics are greatly weathered basaltic rocks	390
10.	Glacio-fluvial sandstone	32
11.	Tillite	81
12.	Glacio-fluvial sandstone	75
13.	Characteristic tillite crowded with erratics	272
14.	A sand phase tillite	112
15.	Typical tillite, rich in large erratics, many of which are striated	704
	Total glacigene formation	3,098

16. Post-glacial slates, striking N. 12° E. and dipping west 33°.

Several hundred feet above the upper surface of the foregoing glacigene beds, intercalated in this slate formation are thin bands of limestone, then more slates and finally a thick formation of crystalline limestone at possibly 800 feet above the base. Dip here 36° to W.

THE POST-GLACIAL RECORD WITHIN THE AREA UNDER CONSIDERATION

These outcropping belts of glacigene accumulations are each followed by a corresponding succession of post-glacial sediments. Namely laminated rock-flour silts below, passing upward into flaggy beds, among which are occasional bands of a somewhat calcareous nature; these in turn finally lead to massive limestones. This also, it will be noted, is the order of succession above the Sturtian Tillite near Adelaide, which locality is some 330 miles further south. Here, however, the laminated slates formation is much less thick, while the limestone development is vastly greater and more varied.

On my second visit to the Mount Jacob area, I did not re-measure the post-glacial succession above the Mount Jacob belt; such data as appear in my earlier paper (Mawson, 1934), though hurriedly secured, should be a satisfactory record up to the faulted area where chocolate shales appear; refer to item 10 of that record. Summarized, the overlying beds there stated include from below upward about 1,250 feet of laminated slates and flaggy calcareous slates followed by over 2,000 feet of beds highly calcareous. These latter are massive limestone below, in part siliceous and dolomitic, passing above to flaggy, banded limestones with associated argillites, which bear the characteristic features of shallow water accumulations. They are rich in oolitic and pisolitic structures, as well as exhibiting several stromatolithic forms corresponding to types often referred to as records of calcareous algae. These latter can be seen also in the face of the Nepowie Rampart a little to the north of Balcanoona homestead.

The argillites and limestones of this belt are surprisingly free from any form of advanced metamorphism such as has affected their equivalents in the Umberatana-Yudanamatana region some 20 miles to the west-north-west.

THE GLACIAL RECORD

It will be observed that the measured thickness of the glacigene belt at Mount Jacob is only 2,447 feet, while at Mount Warren Hastings it is 3,098 feet. Perusal of the succession suggests that there is some indication of a rough correspondence in the deposits of the two localities, if read downwards from the top in each case. This suggests that the underlying surface upon which the glacial sediments were deposited stood at a higher level at the Mount Jacob location than was the case further to the west; perhaps a result of the volcanic accumulations in the former locality.

Details already listed of the changing nature of the glacigene accumulations illustrate the interbedding of true tillites with glacio-fluvial deposits. The latter range from true varved sediments and well-graded sandstone, to water deposited arenaceous and argillaceous beds with occasional embedded erratics. The most massive tillites met with constitute the later depositions; there the erratics reach unusually large dimensions. Dr. Woolnough (1926) mentions having observed, in the more southerly extension of the Mount Jacob belt, a vitreous quartzite erratic some 9 feet in length.

The glacio-fluvial sediments embedded in the glacigene succession are not anywhere of great thickness, so that they cannot be construed as necessarily inferring an interglacial climatic break; they may have resulted from purely local conditions. There is therefore in this area nothing corresponding to the thick interglacial Willyerpa quartzite formation of the Bibliando Dome, which is distant little more than 100 miles to the south. As these glacial beds are all of one epoch, and as they are followed by a sedimentary sequence corresponding with the post-Sturtian succession, we conclude that the Mount Jacob tillites are of the Sturtian epoch, not of the earlier Bibliando (Mawson, 1948) period.

Erratics embodied in the glacigene deposits include some granites and porphyries so closely similar to types met with *in situ* in the Mount Painter complex that it seems certain that they were in fact derived therefrom. These are mainly both grey and brown acid porphyries and both light grey and reddish granite. Less often gneiss and schist are encountered.

One quite remarkable erratic recorded is itself a tilloid rock, of which there is little doubt that it is actually a tillite. Thus the existence of an earlier glaciation appears to be evidenced.

Commonest of all are quartzites, and of them one type appears to be identical with the rock constituting the great quartzite formation overlying the central older Precambrian complex in certain localities, such as along the Arkaroola near the junction of Radium Creek.

Low down in the succession erratics of dolomite and limestone are remarkably abundant; a common type closely resembles a limestone of the underlying series.

In the Mount Jacob area the lowest part of the glacigene belt is remarkably rich in fragments of the underlying basic igneous rocks. This leaves no doubt but that the ice responsible for the accumulation overrode areas of that basalt.

These facts are evidence of the existence of ice-covered land in the vicinity of Mount Painter during the Proterozoic glaciation. It is not necessary to look

to the Gawler Ranges, as suggested by Howchin, for the source of erratics of red to brown acid porphyry, for occurrences of the kind do occur in the neighbouring Mount Painter complex.

THE PRE-GLACIAL RECORD

The sediments underlying the glacial formation are arenaceous and argillaceous flaggy beds with much interbedded dolomite and magnesite. This corresponds to the magnesitiferous formation met with beneath the Proterozoic tillite in many other parts of South Australia, for example with that recorded (Mawson, 1947) west of Copley and at Mundallio Creek. The extensive development of sedimentary deposits of pellet magnesite (see Mawson and Dallwitz 1945, p. 23) below the Mount Warren Hastings belt of tillite is specially noteworthy. We did not meet obvious magnesite beds below the Mount Jacob tillite outcrop, doubtless owing to the very narrow belt exposed to view.

The pre-glacial basaltic igneous activity (Mawson, 1926) on a considerable scale exhibited below the Mount Jacob belt and its absence in the section 8 miles to the west is evidence of its local nature.

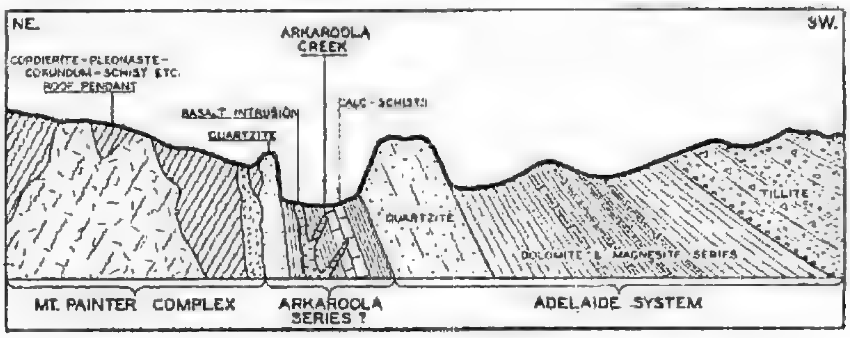

Fig. 3

By following the Wywyana[1] down to its junction with the Arkaroola, thence to the junction of Radium Creek, a complete cross-section of all underlying sedimentary formations between the tillite and the old Mount Painter complex is traversed (see sketch section, fig. 3). First in the downward sequence comes the magnesitiferous dolomite-bearing series, then a massive quartzite formation which should correspond with the Emeroo Quartzite (Mawson, 1947) of the western Flinders Ranges. Next comes an older succession: argillites and limestone, in part richly dolomitic and sideritic, overlying a basal quartzite. Associated with this section of the record is rather abundant basalt in part, at least, intrusive. Beneath this older group of sediments are the granites, gneisses and granulites of the Mount Painter complex.

The oldest series of sediments mentioned above is referred to in the sketch-section as the Arkaroola Series. It is everywhere greatly metamorphosed. In some of its course the quartzite is rendered almost "vitreous". The calcareous formation has been converted to actinolite-phlogopite-siderite schists and marbles. Calcareous slates have been changed to scapolite-rich schists.

We have met a corresponding succession in other localities when passing into the Mount Painter complex. In some other areas, this basal quartzite has been feldspathised and otherwise incorporated into the underlying gneissic system.

Roof pendants (Mawson 1923, p. 376) in the red granite east of Mount Pitts, composed of corundum, pleonaste and cordierite schists, appear to be highly metamorphosed fragments of this series.

[1] This creek is spelt variously on maps in circulation. However, the spelling as here given is that advised as correct usage by Mr. Greenwood, proprietor of that area of country.

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DESCRIPTION OF PLATES

PLATE xxii

Fig. 1—General view of the outcropping magnesite-dolomite-bearing series underlying the glacigene sediments. View looking south-west from a point about a mile north-west of McLeish's Well.

Photo by R. H. Jones

Fig. 2—General view of the lower part of the outcropping glacigene sediments where they overlie the magnesite-dolomite-bearing series about 1¼ miles west-north-west of McLeish's Well. The base of the glacigene beds is the tillite knob showing as a dark patch near the left margin of the picture.

Photo by R. H. Jones

PLATE xxiii

Fig. 1—The top limit of the tillite, where is appears as a cliff face capped by a thin band of limestone followed by a thick series of laminated shales. Photographed in creek bed on the western side of the Mount Jacob Range at western end of section.

Photo by R. H. Jones

Fig. 2—The top limit of tillite on the western side of the Mount Jacob Range and west end of section. Here the thin band of limestone and slates capping the tillite has been eroded back to reveal a fossil moraine surface studded with large erratics.

Photo by R. H. Jones

Fig. 1
Dolomitic series underlying the glacigene belt of Mount Warren Hastings.

Fig. 2
Lower portion of the Mount Warren Hastings glacigene series

Fig. 1

Glacio-fluvial sediments overlying the upper limit of the Mount Jacob tillite.

Fig. 2

The original surface features of the Proterozoic tillite uncovered by erosion of overlying glacio-fluvial sediments.

THE SIGNIFICANCE OF THE OCCURRENCE OF FOSSIL FRUITS IN THE BAROSSA SENKUNGSFELD, SOUTH AUSTRALIA

BY PAUL S. HOSSFELD

Summary

In a paper read before this Society in 1935 (Hossfeld, 1935) the writer, on page 51, referred briefly to the occurrence of lignitized fossil fruits below the present surface of the Tanunda Plain. These fruits were obtained at a depth of 320 feet below the surface from a bore just over two miles from Tanunda, in a direction a little east of south, on Section 650, Hundred of Moorooroo, South Australia, on the property of Mr. H. A. Lindner, who made the specimens available to the writer.

THE SIGNIFICANCE OF THE OCCURRENCE OF FOSSIL FRUITS IN THE BAROSSA SENKUNGSFELD, SOUTH AUSTRALIA

By PAUL S. HOSSFELD

[Read 11 November 1948]

In a paper read before this Society in 1935 (Hossfeld, 1935) the writer, on page 51, referred briefly to the occurrence of lignitized fossil fruits below the present surface of the Tanunda Plain. These fruits were obtained at a depth of 320 feet below the surface from a bore just over two miles from Tanunda, in a direction a little east of south, on Section 650, Hundred of Moorooroo, South Australia, on the property of Mr. H. A. Lindner, who made the specimens available to the writer.

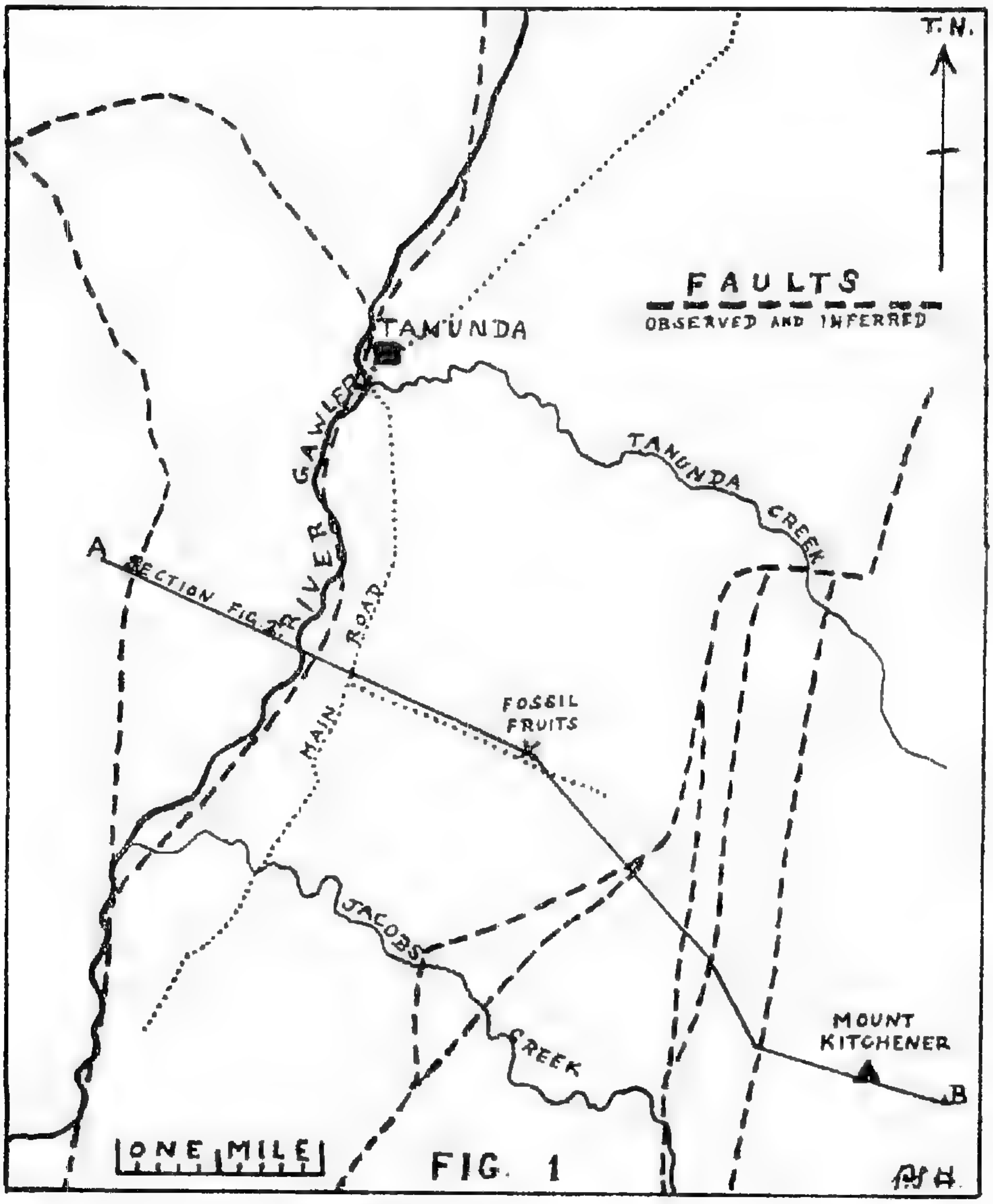

FIG. 1

They have been described and identified by Miss Helen T. Paterson, B.A., who is responsible also for the sections and drawings. The descriptions and illustrations are incorporated in the present paper.

A plan and a section are included in order to demonstrate the writer's conclusions regarding the structure of the area.

The area described in this paper consists of the southern part of the Tanunda Plain, the lowest part of the area, and the higher areas to the east and west. The eastern section includes part of the Barossa Ranges in the vicinity of Mount Kitchener, and the western section consists of part of the Gomersal Plateau.

As will be noted from the section the area is one of diversified relief, produced by the differential movements of fault blocks and their subsequent dissection and erosion. The area appears to have formed a part of the extensive Australian Pre-Miocene Peneplain. Warping and block-faulting, commencing probably in the Early Miocene in some areas, and continuing episodically until Recent times, have dismembered the region and destroyed much of the pre-existing drainage.

The trough faulting which took place in this area resulted finally in the development of the Mount Kitchener Horst, descending by a series of step-faults to the lowest part of the fault basin on which Tanunda is situated, and ascending on the western side by two or more step-faults to the comparatively low Gomersal Plateau. The maximum vertical movement known is in the vicinity of 1,400 feet, the height of Mount Kitchener being 1,965 feet, and the fossil fruit deposit approximately 560 feet above sea level. The Gomersal Plateau, before recent dissection partially destroyed it, appears to have had an elevation of between 850 and 900 feet above sea level.

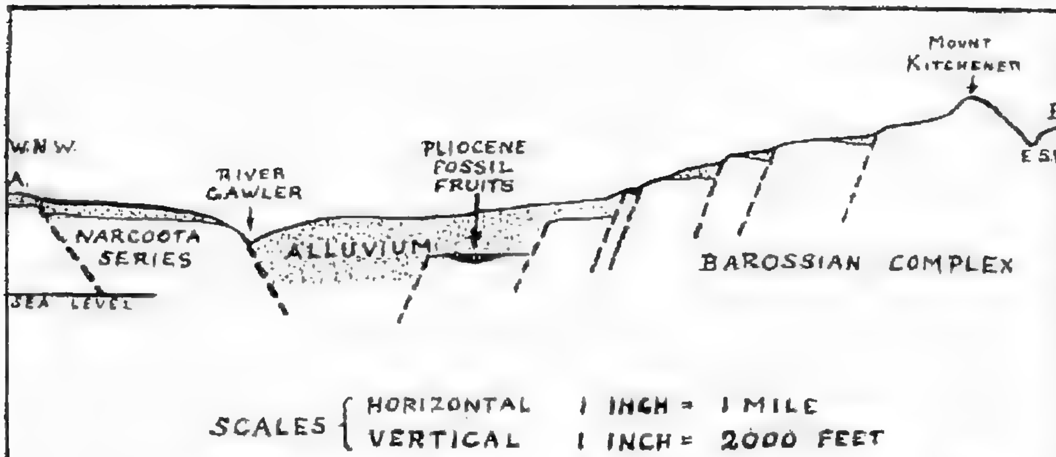

FIG. 2

All of the above fault platforms, the postulated positions of which are marked on the plan, are covered to some extent by alluvial deposits, which mask some of them completely. Thus the existence of the fault block on which the fossil fruits occur, and which will be referred to as the Kabminye Block, could not be proved nor its depth determined until the bore supplied the necessary evidence.

The fertile plain on which the towns of Nuriootpa and Tanunda and a number of villages are situated, owes its origin to the filling of a fault trough, chiefly by alluvial deposits from the Barossa Ranges which form its steep eastern margin.

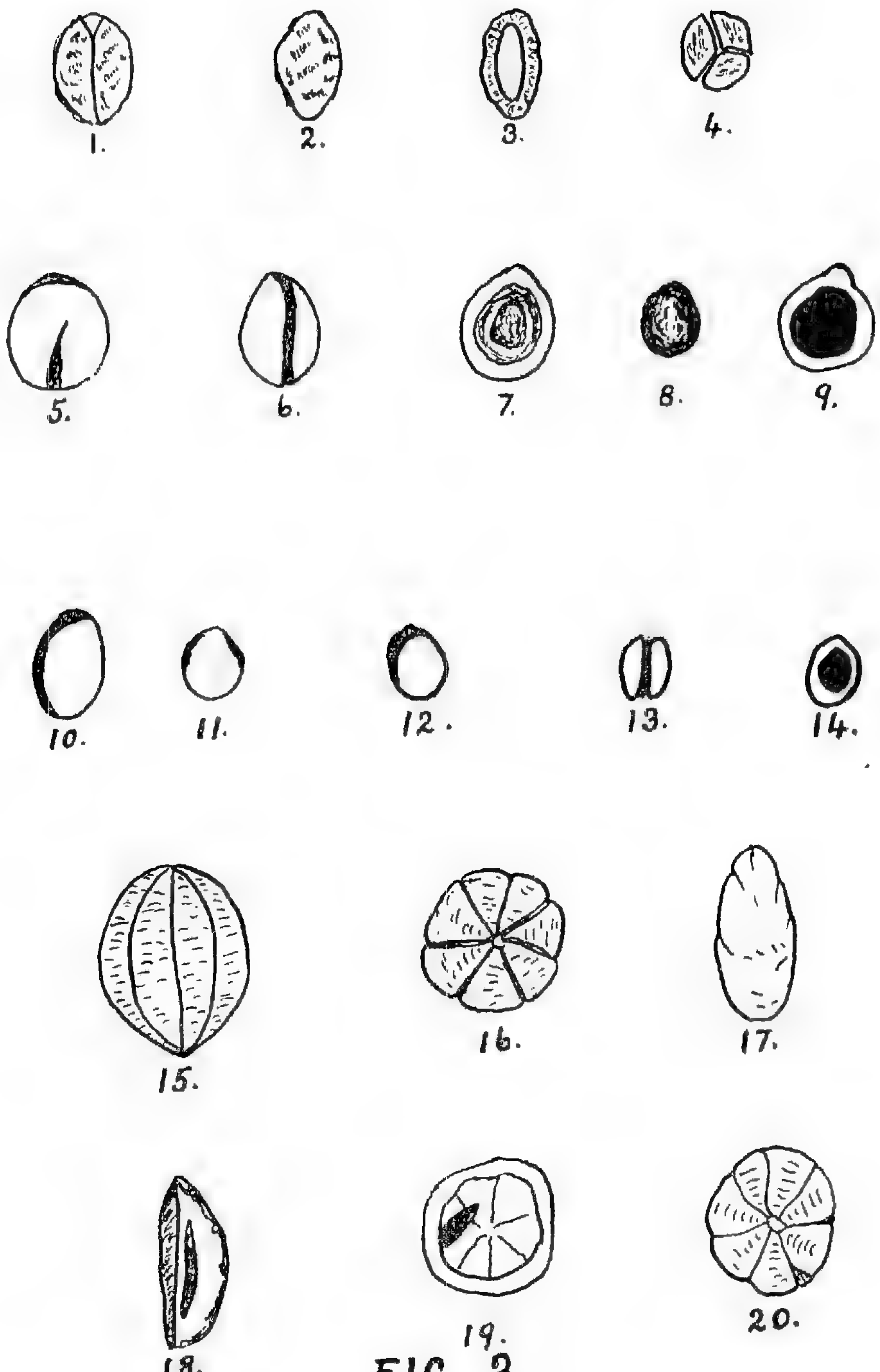

FIG. 3.

Phymatocaryon Mackayi—Fig. 1, Whole fruit presenting sutural edge. Fig. 2, Valves separated, external view. Fig. 3, Valve, inner side. Fig. 4, Whole fruit showing its summit.

Concotheca turgida—Fig. 5, Whole fruit. Fig. 6, Whole fruit showing sutural side. Fig. 7-9, Valves separated, with shrivelled seed. Fig. 10-12, whole fruits. Fig. 13-14, Valves external, internal.

Pleioclinis Couchmanii—Fig. 15, Side view of fruit. Fig. 16, Fruit seen from below. Fig. 17-18, Showing valves. Fig. 19, Transverse section showing seed. Fig. 20, Fruit seen from above.

The down-faulting and warping which produced this fault trough extend much further, and although not marked by the deposition of the deep alluvium characteristic of the Nuriootpa-Tanunda Plain, these extensions are so obviously part of the same system of crustal deformation that they have been grouped by the writer under the term "Barossa Senkungsfeld" and will be described and referred to as such in a paper which is being prepared.

The following descriptions, identification, sections and illustrations have been supplied by Miss Helen T. Paterson.

In classifying the specimens Miss Paterson retained the nomenclature used by Baron von Mueller, but as his work had not been revised according to the present knowledge of our flora the affinity to the existing genera has been shown where possible.

DESCRIPTION OF FOSSIL FRUITS FROM SECTION 650, HUNDRED OF MOOROOROO, SOUTH AUSTRALIA

Family SAPINDACEAE

Phymatocaryon Mackayi Mueller

Phymatocaryon Mackayi, F. v. Mueller, 1874, p. 11, 12, pl. ii, fig. 1-15.

Two specimens of an oval drupaceous fruit, somewhat pointed, with an irregular muricated putamen, 3-valved. The furrows run in symmetrical form from base to apex. One specimen is very compressed as though subjected to pressure. These fruits resemble the living forms of *Elaeocarpus*, for example, *E. grandis*, and correspond to those described by Baron von Mueller, 1874-1883, in his Observations of New Vegetable Fossils of the Auriferous Drifts, as *Phymatocaryon Mackayi*, and by Henry Deane in his Tertiary Fossil Fruits from Deep Lead, Foster, South Gippsland, 1923, p. 490, pl. lx, fig. 13-16.

Several fruits of this genus are also described by Ettingshausen, Tertiary Flora of Australia, 1888, p. 157, pl. xiv, fig. 3, 4, 5, 5a; p. 63, pl. vi, fig. 9-12. These were collected from Beaconsfield, Tasmania; and Elsmore, New South Wales.

Concotheca turgida Mueller

Concotheca turgida F. v. Mueller, 1874, p. 42, pl. x, fig. 6-12; Deane, 1923, p. 491, pl. lx, fig. 11, 17-21.

Several small capsular fruits occur, globular in shape, cavity deep and round. Size circ. ½" long. Valves show an acute line at the edge and a partial aril or prominence. These fruits resemble those found at Nintingbool in the Older Pliocene drift and also at Tangil, as described by Mueller under *Concotheca turgida*. In his Tertiary Fossil Fruits from Deep Lead, Foster, Deane identifies several fruits similar to *C. turgida* as belonging to the family Sapindaceae, the genus *Alectryon* (*Nephelium* F. v. M.) of the present-day flora suggests some affinity.

Pleioclinis Couchmanii Mueller

Pleioclinis Couchmanii F. v. Mueller, 1883, p. 19, pl. xix, fig. 1-11.

Observations—A fruit resembling a nutmeg in appearance, 7-valved, 1" long, ¾" wide, ovate. The outside tubercular and of woody hardness, one seed only, not well developed, oblique with a minute apex and a smooth thin testa.

This fruit is distinguished from the genus *Penteune* by the number of its valves. Similar specimens have been found at Haddon and Nintingbool.

The present-day genus *Pleiogynium*, Engler, shows the same plurality of valves.

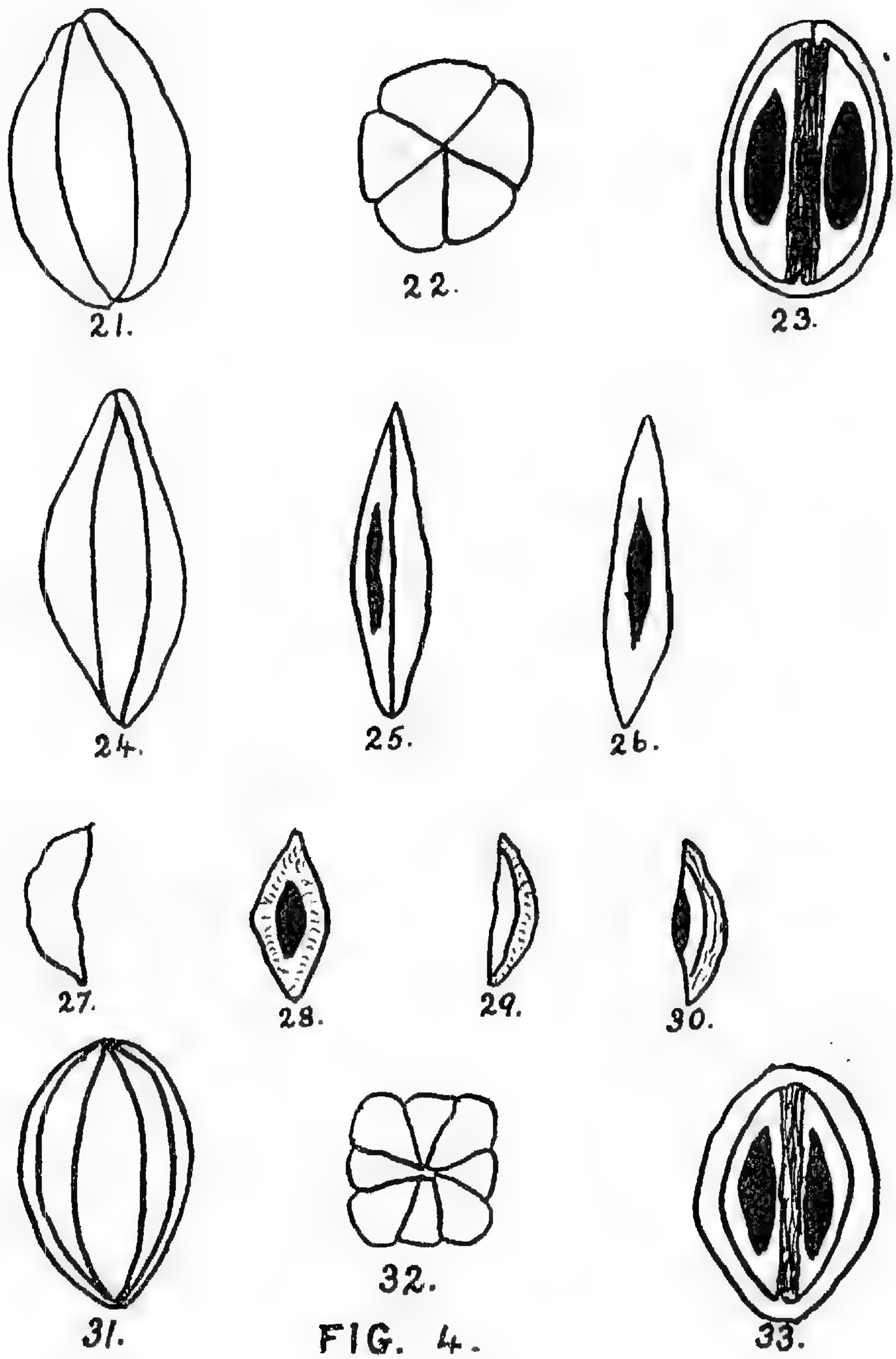

FIG. 4.

Penteune trachyclinis—Fig. 21, Front view of fruit. Fig. 22, End view. Fig. 23, Section showing valves and seeds.

Rhytidotheca Lynchii—Fig. 24, Whole fruit. Fig. 25-26, Valves and seeds. Fig. 27-30, Valves of smaller fruit, external, internal, side views.

Spondylostrobus Smythii—Fig. 31, Whole fruit. Fig. 32, Fruit seen from above. Fig. 33, Section showing seeds.

PENTEUNE TRACHYCLINIS Mueller

Penteune trachyclinis F. v. Mueller, 1874, p. 22, pl. viii, fig. 10-17.

Observations—a large fruit 1½″ long, 1″ wide, broadly ovate; consists of five valves to the base. These are thick and woody, seeds not developed.

Similar fruits have been found at Smythe's Creek and in the Tertiary travertine at Geilston Bay, Tasmania.

Henry Deane in his Fossil Fruits from a Deep Lead, Foster, compares fruits found there with *P. Clarkei*, F. v. M. (1923, p. 490, pl. lx, fig. 1, 2, 3) and the present-day *Owenia venosa*, but points out the difference in the number of valves, only one out of three being 5-valved. These fruits show a similarity in shape and number of valves to the family Meliaceae, which is not represented in Victoria at present.

Family MELIACEAE

RHYTIDOTHECA LYNCHII Mueller

Rhytidotheca Lynchii F. v. Mueller, 1874, p. 15, pl. iv, fig. 1-8.

Observations—Several boat-shaped valves occur, c. ¾″ long and ¼″ wide, with roughened tubercular surface. These resemble the genus *Flindersia*, but its wing-shaped seed in a decomposed state has not been preserved.

In F. v. Mueller's Fossil Fruits a similar type of fruit is figured as *Rhytidotheca Lynchii*. This species shows an affinity to the present-day *Flindersia*. Henry Deane describes and refers two fruits from a Deep Lead, Foster, to *R. Lynchii*, but stresses their resemblance to *Flindersia maculosa*. These valves are of a smaller variety.

Two complete, oblong, capsular fruits, one 1¾″ long, ½″ wide, have each five roughened valves, not echinate, and contain a woody placenta with flat seeds on either side. These fruits may be referred to the same genus.

Family CUPRESSINEAE

SPONDYLOSTROBUS SMYTHII Mueller

Spondylostrobus Smythii F. v. Mueller, 1874, pp. 8-9, pl. i, fig. 1-8; *Ibid*, 1883, p. 13-14, fig. 5A, 5B

Observations—A large fruit, 1¼″ long, ¾″ broad, consisting of four valves with wide ridges at the apex, becoming convex and narrow at the base. Seeds two, free from the valve. Similar fruits have been found at Haddon, Victoria; Orange, New South Wales; and Launceston, Tasmania.

There is no evidence of this type in the present flora; the nearest affinity is found in the conifer *Callitris* and its sub-genus *Frenela;* these plants show a similar verticillus of fruit valves.

DISCUSSION

A review of the available literature suggests that while these fossils appear to be of Pliocene Age, their position within the Pliocene cannot be determined at present.

Further collections and investigations might modify the above age determination. Whatever the final verdict as to their age may be, these fossils supply evidence of the beginning of downwarping and possibly faulting, in the area. The dismemberment of the peneplain in this area appears to have begun by crustal warping, which eventually culminated in the development of block-faulting in

portions of the warped areas. Further to the north, warping produced monoclinal flexures which can still be recognised. If the fossils are definitely of Pliocene Age then the movements must be at least as old as the Pliocene.

These movements have continued episodically until recent times and may not have ceased entirely; alluvial, lacustrine and fluviatile deposits covering the Pleistocene-Recent Period occur in a number of areas in the Northern Mount Lofty Ranges.

There is reason to believe that other deposits similar to the fossil fruit occurrence in the Kabminye Block occur, not only beneath the Nuriootpa-Tanunda Plain, but possibly also in other similar localities such as the Dutton Plain, the Mount Crawford Plain and others.

Although the existence of lignite of Pliocene Age is a distinct possibility, it appears likely that, should such deposits exist, they would be comparatively small, and probably uneconomic because of other adverse factors.

Acknowledgments—The writer is indebted to Mr. H. A. Lindner, of Kabminye, for the loan of the fossils; to Mr. H. B. Lindner for his assistance to the writer in many ways; to Miss Helen T. Paterson for the identification and description of the fossils; and to Mr. W. Riedel for assistance in the age determination of the fossils.

Reference

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THE GEOMORPHOLOGY OF COUNTY VICTORIA, SOUTH AUSTRALIA

BY T. LANGFORD-SMITH

Summary

The geomorphology of County Victoria is analysed on the basis of three distinct zones, known respectively as the Pirie Plains, the Central Highlands, and the North-Eastern Plateau. An attempt is made to interpret certain structural and landform phenomena within these zones, particular attention being paid to the sand dunes of the Pirie Plains and the ridge-and-valley structure of the Central Highlands.

THE GEOMORPHOLOGY OF COUNTY VICTORIA, SOUTH AUSTRALIA

By T. LANGFORD-SMITH*

[Read 11 November 1948]

CONTENTS

ABSTRACT

1. The geomorphology of County Victoria is analysed on the basis of three distinct zones, known respectively as the Pirie Plains, the Central Highlands, and the North-Eastern Plateau. An attempt is made to interpret certain structural and landform phenomena within these zones, particular attention being paid to the sand dunes of the Pirie Plains and the ridge-and-valley structure of the Central Highlands.

2. Attention is drawn to outcrops of Tertiary gravel within the County, and the probable relation of this gravel to Tertiary and post-Tertiary topography and drainage patterns.

3. An attempt is made to correlate tectonic movements that have taken place since the Tertiary.

4. The drainage systems within the County are discussed, and evidence is submitted in support of a "stream capture" theory which would account for anomalies in the course of many of the existing streams.

* Department of Post-War Reconstruction, Canberra, A.C.T

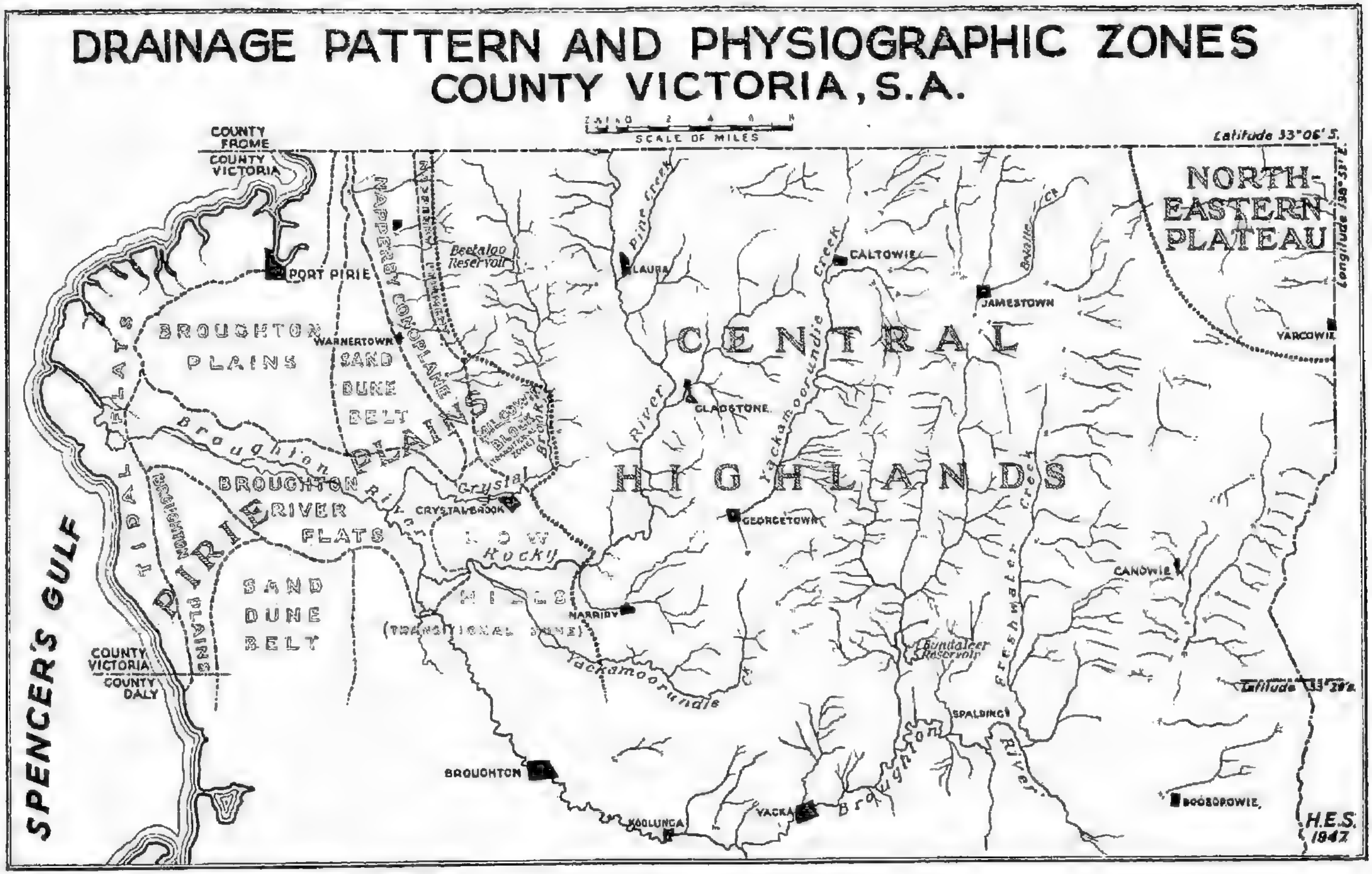

Fig. 1 Drainage Pattern and Physiographic Zones

INTRODUCTION

This is the second paper on the Geography and Geology of County Victoria.[1] It is an attempt to analyse the physiography of the area, and then to interpret, on a geomorphic basis, certain structural and landform phenomena.

Air photos to a scale of four inches to a mile were available for the eastern half of the County, and these were used extensively during the field investigations, and also for mapping details of stream patterns. A contour map of the County was compiled from the photographs with the aid of engineering levels and some aneroid heights, and this has since been published in C.S.I.R. Bulletin No. 188, 1945. The drainage systems in fig. 1 are based on this map.

PHYSIOGRAPHIC ZONES

There are three major physiographic zones in County Victoria: the Pirie Plains, the Central Highlands, and the North-Eastern Plateau (see fig. 1). Of these, the Central Highlands is by far the largest and occupies all the central part of the County. Only a small part of the North-Eastern Plateau (mostly confined to the Hundred of Whyte) is included in County Victoria, but this zone extends over a considerable area outside the County boundaries. The Pirie Plains include the regions between Spencer Gulf and the Central Highlands.

The three zones are discussed in detail as follows:

A. The Pirie Plains

These are defined as the low-lying coastal areas which are bordered on the east by the highlands and on the west by Spencer Gulf.* The parts of this zone in the neighbourhood of the town of Port Pirie have been described in some detail by Martin (1939) in a regional study of the Port Pirie district. Martin has adopted a subdivision of the area which has been extended in the present study to include the whole of the Pirie Plains. The writer is of the opinion that Martin's classification would be difficult to improve, and the only amendments suggested are the insertion of an additional very narrow subdivision, the "Napperby Pediment," and the use of the spelling "plane" in preference to "plain" in "Napperby Conoplain." Martin's subdivision "Pirie Plains" has been changed to "Broughton Plains" to avoid confusion with the larger physiographic zone discussed in the present paper.

With these slight amendments, the classification reads as follows (see fig. 1):

(i) Shoreline	(v) Sand Dune Belt
(ii) Tidal Flats	(vi) Napperby Conoplane
(iii) Broughton Plains	(vii) Napperby Pediment
(iv) Broughton River Flats	(viii) Milcowie Block

(i) Shoreline

Within the limits of County Victoria the coastline is approximately arcuate. Although it is not broken by any major irregularities, there is an intricate network of small inlets and tidal waterways. Mangroves flourish, and give to much of the coastal area the appearance of a tidal mangrove woodland. The coastal plain adjacent to the shoreline is very flat, and the sea very shallow. There is thus an extensive tidal area.

[1] The earlier paper was entitled "The Geology of the Jamestown District, South Australia," Trans. Roy. Soc. S. Aust., 71 (2), 281-295, 1947. The field work for both papers was undertaken by the writer in 1941 and 1942 while a member of a C.S.I.R. Soil Survey Party.

* See pl. xxiv, fig. 1.

The larger inlets are Port Pirie Creek, Fisherman Creek, and Port Davis Creek. Fenner (1931) considers that Port Pirie Creek was once the mouth of the Broughton River, and Martin thinks that Fisherman Creek and Port Davis Creek are also the abandoned estuaries of former rivers. Martin (1942) has noted the presence of submerged off-shore bars in the neighbourhood of the Fisherman Creek inlet. These bars are several feet below sea level.

The characteristics of a shoreline of emergence as outlined by Johnson (1919) correspond very closely with those of the shoreline under discussion. Examination of the dune ridges inland shows that considerable emergence must have already taken place. However, the present existence of off-shore bars is indicative of the *initial* stages of a period of emergence. It is therefore probable that the whole process of emergence has not been continuous, but has occurred in stages which have included minor static periods or even brief periods of submergence.

(ii) TIDAL FLATS

Martin has defined this area as "that lying between sea level and the western limit of the red sandy soils on the (Broughton) Plain to the east." The whole of the area is not continually subject to tidal action; the higher parts are only occasionally flooded, following abnormally strong winds and high tides. Swamps are a feature of the area. The soils are saline and are heavy in texture, cracking extensively when dry. In times of heavy rain the area receives additions of clay and silt which are carried down in suspension from the conoplane which lies eastward. The tidal flats are characterised by the growth of saltbush and samphire.

(iii) THE BROUGHTON PLAINS

These are bounded on the east by the sand dune belt, and on the west by the tidal flats. The plains are divided by the Broughton River Flats into a northern and a southern sector.

The Broughton Plains are found only below the 100-ft. contour. They are not perfectly flat, but include a number of shallow depressions which become swamps after rain. Martin has indicated that these depressions are due to the action of streams which are now extinct. He has found further evidence of past stream action near the town of Port Pirie.

If the Broughton River once flowed to the sea *via* Port Pirie Creek, it must have since passed through a period during which it wandered across various parts of the Plains, and in this case could have been responsible for many of the stream relics seen today.

(iv) THE BROUGHTON RIVER FLATS

These are the flood plains of the Broughton River. They cover an area some 5 miles in width and 16 miles in length, stretching from just west of the town of Crystal Brook to the Tidal Flats near the coast.

There is a rather abrupt break of slope in both the Broughton River and Crystal Brook, as each of these streams emerges from the hills of the hinterland on to the Pirie Plains, and in consequence there has been considerable deposition of suspended material. During floods a large part of the Broughton Flats is covered by a sheet of water, which in many places does not completely drain away or evaporate for some days. With each flooding a fresh layer of silt and clay is deposited.

The flood plains are almost completely flat, falling into the slope category of 0° to 0° 30′.

(v) The Sand Dune Belt

This consists of a series of undulating dunes, which show a tendency to run in a north-south direction, forming a succession of ridges approximately parallel to the coastline. The north-south trend is well defined in the northern sector, near Port Pirie and Warnertown. In the Hundred of Wandearah to the south the dunes are more irregular, although the north-south tendency still persists; they are here more gently undulating than to the north.

The dunes rise to a maximum of about 200 feet above sea level in the south-eastern corner of the Hundred of Napperby. In general, however, it is unusual for the height to exceed 100 feet above sea level. Throughout the area, the crests of the dunes are rarely more than 50 feet above the neighbouring swales; 20 to 30 feet is more usual.

Because of the amount of loose sand that is blowing about at the present time as a result of recent erosion, there is a common impression that the whole dune system is unstable, and that the dunes themselves are migrating. On investigation, however, the majority of the dunes were found to be supporting a stable growth of saltbush, bluebush and acacias, with some mallee. The degree of erosion to which they had been subjected was rarely greater than that required to expose the roots of the acacias. This in itself would indicate that although migration may have taken place in past geological time, there has not been any recent mass movement. Additional evidence was afforded by the profiles of the dunes. Whenever these were examined they were found to conform to those of mature, fixed soils. Grey-brown to brown mallee sand (Wandearah series) was the dominant soil type. Usually there was well-developed limestone rubble in the subsoil, and in some cases a layer of sheet travertine. Features such as these are characteristic only of fixed dunes.

The impression that the dunes are migrating is caused by erosion of portion of the topsoil, which is almost pure sand. This erosion has been instigated by grazing and, in some cases, by cropping which has disturbed the surface and interfered with the normal vegetation cover. It has required very little removal of topsoil to build up large masses of loose sand, which at present are continually drifting. In parts these sand drifts have caused considerable obstruction to road transport, especially in the Hundred of Wandearah.

In the past there has been some tendency to assume that wind is the only eroding element which seriously affects regions such as the Sand Dune Belt. However, there is a growing inclination to place far greater significance than formerly on the relative importance of water erosion in arid and semi-arid areas. Although the greater part of Port Pirie's rain occurs during the winter as a result of the southern low pressure systems, nearly one-third of the yearly total of 13" falls in the period October to March, and much of this in the form of thunderstorms and rain of high intensity. Once soils of light texture such as those in the area concerned have been cleared of their natural cover, they react readily to the erosive effects of heavy rainfall. The compactness of the upper horizon is considerably reduced, and even if there is no actual transportation of the soil it becomes extremely susceptible to wind sorting when dry and commences to drift.

Reports from the Hundreds of Pirie and Wandearah describe abnormal stream flow phenomena in some water-courses after heavy rain, for it would appear that the direction of flow is not always constant. Since the gradient of the water-courses in these areas is very slight, any drifting of loose material along the beds of the streams is likely to have a damming effect in the event of heavy rain, resulting in the ponding of water. In such a case, unless the water breaks

through the obstruction and resumes its former course, it will eventually build up until it finds a fresh outlet upstream, and a new stream system will come into being.

The trend of the sand dunes parallel to the coast, their "fixed" character, and their relation to the shoreline all indicate that they are old shore ridges, representing successive stages in the history of a prograding shoreline. The probability that they came into being following emergence of the coastal area has been noted by Martin, who also mentions a view which has been expressed to the effect that the dunes came into existence following man's settlement of the area. The latter hypothesis would be completely untenable in view of evidence available concerning the fixed nature of the dunes, although there is little doubt that most of the sand at present drifting is the result of erosion which followed early human activity.

(vi) The Napperby Conoplane

The Napperby Conoplane and Pediment are transitional zones between the Pirie Plains and the South Flinders Range. Martin has included in his Conoplane the areas approximately between the 200′ and 500′ contours. The writer has inserted a "Pediment Plane" in the upper limits of the zone, and this has reduced the upper boundary of the Conoplane to about 400′.

The Conoplane consists of a fairly regular series of parallel alluvial cones, composed of material brought down from the steep western scarp of the South Flinders Range by short fast-flowing consequent streams. The longitudinal profile of each of these streams shows an abrupt break of slope at the foot of the Pediment Plane, where a vast quantity of coarse rock material and sediments has been deposited. The present streams are not entirely responsible for building up the higher parts of the cones, for here there is a considerable accumulation of talus and colluvial material which has been brought down directly from the scarp and carried across the Pediment Plane.

Further down the alluvial material becomes progressively finer in texture, and where the cones fan out on the Pirie Plains it consists almost entirely of silt and clay. Each heavy rain results in the deposition of a fresh layer of material, and roads across the lower parts of the Conoplane are frequently impassable after rain as a result of freshly deposited sediments.

In the lower part of the alluvial cones the streams lose the well-defined channels which are characteristic of their upper courses, and numerous distributaries appear.

(vii) The Napperby Pediment

This subdivision is mainly of academic interest, for it is very much smaller in area than the others. It is found at the base of the western scarp of the Flinders Range in the Napperby region and occurs as a narrow, steeply sloping plane, which grades into the Conoplane in its lower limits (see pl. xxiv, fig. 2). The width is variable, ranging from a quarter of a mile to two miles. The angle of slope is also somewhat variable, but averages about 6°.

A useful section through the plane is shown by the Napperby Creek. This exposes bedrock in many places, particularly in the upper limits.

It is significant that the Pediment Plane is too steep to permit accumulation of alluvial and colluvial material, and yet on the whole is not subject to downward degradation like the mountain scarp. At the same time it is underlain by bedrock which is part of the range system. It is therefore probable that the plane is dominantly one of "lateral planation," corresponding to Johnson's definition (1932) of a pediment plane.

From evidence of shatter zones in the bedrock seen in the creek beds near the lower limits of the Pediment, it would appear that the junction between the Pediment and the Conoplane may represent the approximate position of the original line of fault, and that the mountain scarp has retreated eastwards a distance equivalent to the width of the Pediment—that is, between a quarter of a mile and two miles.

(viii) The Milcowie Block

Like the Napperby Pediment, the Milcowie Block is transitional between the Pirie Plains and the Central Highlands. It is a relatively small area between Crystal Brook and the southern extremity of the South Flinders Range. Martin has noted that its western boundary coincides approximately with the 450′ contour, and is represented by a low but well-marked scarp. The Crystal Brook-Hughes Gap road approximately constitutes the eastern boundary. The maximum height of the area slightly exceeds 600 feet above sea level, the average being about 500 feet.

Where the Sand Dune Belt adjoins the Milcowie Block, it is appreciably higher than the remainder of the Belt, and it is possible that the uplift which produced the Block was responsible for the extra elevation of the sand dunes in this area. If this be so, the Milcowie Block must have been uplifted subsequently to the major faulting responsible for the adjoining South Flinders horst, for the sand dunes are more recent in origin than the fault scarp.

B. The Central Highlands

(i) General

Inland from the Pirie Plains is an upland zone consisting of a complex series of alternating ridges and valleys. Except for a small area in the vicinity of the Bundaleer Reservoir, these ridges and valleys are parallel and have a remarkably consistent north-south trend.

Three high ranges are included in this "ridge-and-valley" area. They are the South Flinders Range, the Campbell Range, and the Browne Hill Range: both of the latter are technically within the North Mount Lofty Range system. The highest of the ranges is the South Flinders, which reaches a maximum of 2,528 feet at the Bluff.

Bordering the northern part of the Browne Hill Range in County Victoria, the upland area gradually loses its "ridge-and-valley" structure and merges into a plateau area. This has been termed the "North-Eastern Plateau" for the purposes of the present study, and is discussed later under this heading.

(ii) Ridge-and-Valley Structure

In the past there has been no detailed investigation of this structure, which is the most prominent physiographic feature of County Victoria (see pl. xxiv, fig. 3 and 4).

Fenner (1931), commenting on the popular view that the ridge-and-valley structure has been due to tilted blocks, draws attention to the possibility of differential erosion along the strike of hard beds as an explanation. He notes that in any case the true origin of the structure has yet to be determined. Tilted blocks have played an important part in producing much of the structure of the Mount Lofty Ranges to the south, but except for a relatively small area in the vicinity of the South Flinders horst, the structural geology of County Victoria is notably different from that of ranges near Adelaide. Over a large part of the eastern portion of the County, the writer's investigations (Langford-Smith 1947) have shown conclusively that the tilted block theory is not tenable. Here there has been very little major faulting, and the country is folded into a series of synclines and anticlines. Some of the present valleys conform to the original

synclines. Examples of these may be found in the wide valley containing the township of Caltowie, and that containing the headwaters of Belalie and Freshwater Creeks. Other valleys are eroded anticlines, an example being the broad valley in which Jamestown is situated.

In almost all instances, the crests of the ridges are strengthened by outcrops of highly resistant quartzite. These are particularly prominent in the eastern and western borders to the Jamestown valley, which are represented respectively by the Browne Hill and Campbell Ranges. These ranges are the upfolded margins of the adjoining synclinal valleys, and the quartzite which outcrops prominently in the ridges is associated with the tillite series and its subglacial beds. Differential erosion has therefore played an important part in the development of the existing ridge-and-valley structure.

The folding which produced the original synclines took place during one of the great Palaeozoic mountain-building periods (Mawson, 1942). Geological sections of the Jamestown district (Langford-Smith, 1947) indicate the vast amount of erosion that must subsequently have occurred to produce the Tertiary peneplane. In the ridge-and-valley areas of the Central Highlands the main features of this Tertiary landscape have been preserved to the present day. Some estimate of the minor degree of modification which has taken place can be made by a study of the Tertiary gravels and laterites which occur as residuals.

(iii) South Flinders Fault-Line Scarp

The western scarp of the South Flinders Range is a particularly prominent feature. The scarp is very precipitous, and in the vicinity of the Bluff it rises 2,000 feet within two miles, attaining a maximum height of 2,528 feet above sea level. The line of the scarp is particularly straight, running almost due north and south.

Evidence from gorges and creek beds indicates that the position of the fault or series of faults which have been responsible for this elevated block is comparatively close to the present scarp, and the latter must therefore be classified as recent. As was noted earlier, it is probable that the original line of fault corresponds to the lower limit of the Pediment Plane. This was shown to be the case in the Port Germein area, some 10 miles to the north, but within County Victoria conclusive evidence could not be obtained in the time available in the field.

Apart from the main line of fault, there has been considerable minor faulting, evidenced by shatter zones along the base of the cliffs.

C. The North-Eastern Plateau

From the physiographic point of view, the North-Eastern Plateau does not have the same interest as the other two zones in County Victoria. Also, although the plateau extends for some considerable distance beyond the County boundaries, the part within the County itself is small, being largely confined to the Hundred of Whyte. For these reasons, only brief mention is made of the zone in the present study.

These is no distinct boundary between the Central Highlands and the North-Eastern Plateau. The typical "ridge-and-valley" structure of the former is gradually replaced by a more irregular pattern, and the relative relief between ridges and valleys becomes much smaller. In the far north-east corner of the County there are wide areas of comparatively level land.

The altitude of the Plateau is for the most part between 1,700 and 2,100 feet above sea level. The zone is dominantly an area of internal drainage. There are no very distinct drainage lines, and the streams which do exist flow only after rain. This is largely because of the low rainfall, which is less than 16″ for the

whole zone, and less than 14" in the north-east corner of the County. Near the township of Whyte-Yarcowie are two playa lakes which contain large quantities of water after rain. In the summer months most of this water evaporates, leaving a dry salty surface.

The soils in many parts of the Plateau zone have saline tendencies, and there are appreciable areas of halomorphic soil (Pirie series).

The hills and ridges within the zone are more rocky than in the Central Highlands. They have little soil or vegetation cover and present a very barren appearance.

TERTIARY GRAVELS

There are a number of relics of Tertiary gravel in County Victoria. For the most part these outcrop as residuals on low, rocky ridges within the broad north-south valleys of the Central Highlands.

Howchin (1931-33) in his "dead-river" hypothesis claimed that these gravels represent the courses of old north-south rivers which flowed during the late Tertiary, and which were truncated by the Peterborough-Olary upwarp. He considered that the presence of gravels throughout the valleys of the Mount Lofty Ranges inferred that a major river system once flowed right through these parts to the southern coast.

As far as the Mount Lofty Ranges near Adelaide are concerned, the arguments against this theory seem fairly conclusive (Fenner 1939, Sprigg 1945-46). However, the present writer is inclined to the view that although Howchin's hypothesis is far too sweeping in its claims, it may have elements of truth in the case of the northern areas in the neighbourhood of County Victoria.

From study of the "ridge-and-valley" structure of the County Victoria region, it would seem that there must have been some form of north-south drainage prior to the Peterborough-Olary upwarp. This drainage may have been related to the present Lake Torrens area, but there is no evidence to the effect that it was part of the great north-south river system of the Tertiary which was later ponded back to form a central Australian lake (David's "Lake Dieri"). However, even a small local drainage system would have left relics of stream action, and it is not unreasonable to suppose that some of these relics would still be preserved.

Some of the gravels from the low residual ridges within the broad valleys of the Central Highlands are typical of present stream conglomerates (see pl. xxv, fig. 1), except that they have been somewhat silicified. The pebbles contained in these specimens are well rounded and have certainly been stream-worn. Gravels such as these are quite distinct from other gravels which occur on similar residual sites (in fact, sometimes on adjacent sites), and which contain much angular material. The writer has followed outcrops of the old conglomerate for considerable distances through the valleys near Jamestown, and it is significant that the outcrops followed a line which would be the logical course of earlier longitudinal streams. It was also noted that the height of these residual outcrops above the present baseline in the valleys *increases from east to west*. For example, a typical gravel outcrop in the Hundred of Whyte is 30 feet above the present stream bed. A similar outcrop in the Hundred of Belalie is 130 feet above the valley baseline. This is concurrent with the rainfall, which also increases very markedly from east to west. The inference is that erosion during Pleistocene and Recent times has been proportional to the incidence of the rainfall.

Fenner (1939), from his examination of ancient gravels in the Adelaide region, concludes that they consist of re-sorted fault-apron material and relics from streams which meandered over the pre-Miocene peneplane. He considers

that the deposits have largely "been formed by streams which cut back into the scarp faces and flowed at right angles to the supposed directions of the hypothetical ancient streams." He therefore believes that the dead river theory "is in the main an untenable interpretation of the facts."

However, in County Victoria, the location of the "conglomerate" type of gravels on residual sites in the centre of broad synclinal and eroded anticlinal valleys shows that they could not be re-sorted fault-apron material. Also, the definite longitudinal pattern of the outcrops down the central parts of the valleys would indicate that they were formed *in situ* by streams which flowed immediately prior to the Peterborough-Olary upwarp. It is therefore contended that a modified version of Howchin's hypothesis may be applicable to the County Victoria region.

It is considered that the more angular silicified gravels found on residual sites both within the broad valleys and in some cases on the adjoining valley slopes are relics of Tertiary laterisation, and that the silicified "conglomerate" type of gravel has also been subject to laterisation. Bryan (1939) and Whitehouse (1940) have shown how laterisation can be responsible for the silicification of sediments. They believe that the "billy" deposits of Queensland were formed during wet, warm periods in the Pliocene.

In view of the fact that laterites are formed largely in areas of impeded drainage, it would not be incongruous to find pure laterites adjacent to "laterised" old stream gravels in sites which must have represented the Tertiary valley floor.

Since most of the ridges in County Victoria have a resistant core of silicified quartzite, it is unlikely that they have changed in form very noticeably since pre-uplift time. Therefore it should not be difficult to make an approximate reconstruction of the late Tertiary topography by mapping all the existing residuals of laterite or laterised sediments, particularly in the Central Highlands where there has been little or no major Tertiary or post-Tertiary faulting.

TECTONIC MOVEMENTS

Main Tectonic Associations

County Victoria is an area transitional between the North Mount Lofty and the South Flinders Ranges. Largely as a result of this it exhibits structural features which can be related to four significant tectonic movements: the Peterborough-Olary upwarp, the Flinders horst movements, the Mount Lofty horst movements, and the periodic uplifts of Pleistocene to Recent time. First, there is the high plateau country to the central north and north-east, which is a result of the Peterborough-Olary upwarp; secondly, the South Flinders Range in the Port Pirie area, which is part of the Flinders horst; thirdly, the mountains and ridges of the Central Highlands which dominate the central and southern parts of the County, and which although related to the Peterborough-Olary upwarp are also associated with the Mount Lofty horst movements; and finally, the coastal plains which exhibit evidence of uplift from Pleistocene to Recent times.

The Gulf area to the west of the County, which constitutes part of the Spencer-Vincent Sunkland, is a result of the Flinders and Mount Lofty horst movements.

Age of Movements

There has been considerable speculation in regard to the nature and age of these tectonic movements. The 1939 A.N.Z.A.A.S. committee on "Structural and Land Forms" agreed upon a tentative correlation for the major Tertiary and post-Tertiary movements in South Australia. This involves a gentle uplift period

at the conclusion of the Miocene, accelerated uplift in the Pliocene followed by a period of stillstand, and then further differential movement in the Pleistocene continuing in special cases into Recent times.

Since 1939 there has been a tendency to favour a more recent age for these movements. It has been suggested (Brown 1945) that the period of accelerated uplift may have been the early or middle Pleistocene instead of the Pliocene. Brown quotes Fenner's view (1931) that the Peterborough-Olary upwarp predated the more violent Flinders and Mount Lofty horst movements, and remarks that the upwarp may have begun in the late Pliocene.

Mawson (1942) has suggested that the Flinders and Mount Lofty horsts may be the result of two distinct movements, the former being the earlier.

The Central Highlands of County Victoria, with the exception of the South Flinders Range near Port Pirie, are technically part of the North Mount Lofty Ranges. However, from the geomorphic point of view they do not appear to be closely associated with either the Flinders or Mount Lofty horsts, and are more directly related to the Peterborough-Olary upwarp. The writer's stratigraphical investigations (1947) of the Central Highlands in the Jamestown area showed that there had not been any appreciable block faulting in this region, and there was no evidence of major post-Tertiary tectonic activity other than simple uplift. Since this area merges into the Peterborough-Olary ridge, a large part of the uplift must have been due to the Olary upwarp movements. However, the area may have been further uplifted at the time of the Flinders and Mount Lofty horst movements.

Evidence of Recent uplift in County Victoria, which was discussed in an earlier section, is common to a large part of the South Australian coastline. Crocker (1946) has discussed in some detail the evidence of uplift in the South-Eastern districts and on Yorke Peninsula, as indicated by sand dunes and raised beaches.

The following is submitted as a tentative correlation of tectonic movements in County Victoria from the Tertiary onwards. The table is based on the writer's observations within the County, co-ordinated with recent research elsewhere in the State. Brown's suggestions regarding the age of the main movements have been adopted provisionally.

Late Pliocene (or early Pleistocene?)	Gentle upwarp of the Peterborough-Olary ridge, accompanied by uplift of the adjoining peneplane area at present represented in County Victoria by the Central Highlands (with the exception of the South Flinders Range).
Early to Middle Pleistocene	(a) Major uplift, producing the Flinders horst, which included the extremity of the South Flinders Range near Port Pirie. Possibly further uplift of the Central Highlands. (b) Renewed major uplift, producing the Mount Lofty horst, and probably associated with this, renewed gentle uplift of the Central Highlands.
Middle Pleistocene to Recent	Continued periods of minor uplift, reflected by the sand-dune system on the Port Pirie Plains. Evidence from the Port Pirie area indicates that these movements are still in progress.

"Double Planation" Hypothesis

Fenner (1931), following a suggestion by Douglas Johnson, drew attention to the possibility of a "double planation" hypothesis to explain certain existing phenomena in the Mount Lofty Ranges. This hypothesis involves two periods

of major uplift, each followed by a period of peneplanation. Fenner considered that there may have been a prolonged period of stillstand between the two uplift periods, during which much of the mature landscape of the Ranges (such as the Upper Torrens valley) was produced.

It was noted in the A.N.Z.A.A.S. Report of 1939 that supporting evidence for this theory had not been forthcoming, and subsequently certain workers, notably Sprigg (1945), tended to discount the hypothesis. However, as a result of some recent work, Sprigg (1946) is inclined to reconsider the question. He notes that laterite occurs in many parts of the Mount Lofty Ranges and stresses the necessity of impeded drainage conditions as one of the pre-requisites of laterisation. Conditions such as these could have occurred during a period of stillstand between two major uplifts.

Further details concerning the age of the laterites in the Mount Lofty Ranges will not only help to clarify the age and nature of the uplift movements in that area, but by correlation with the laterites in the County Victoria region may throw further light on the inter-relation between the Mount Lofty horst movements, the Flinders horst movements, and the Olary upwarp.

DRAINAGE SYSTEMS

General

The drainage divide represented by the Peterborough-Olary ridge is just outside the northern limits of County Victoria. This divide constitutes the boundary between exoreic and endoreic streams.

North of the divide the whole of the drainage is endoreic. For instance, to the north-west, drainage is by way of the Willochra system to Lake Torrens; directly north is a region of local internal drainage, while to the north-east the streams spread out and lose their identity on the Walloway Plains.

South of the divide, as the general slope of the County is from north to south, all the main streams flow in a southerly direction. They are exoreic, for they finally join the Broughton River to enter the sea near Port Pirie.

The accompanying map (fig. 1) illustrates the general drainage pattern of the area.

"Stream Capture" Theory

As noted in a previous section, it would appear that the general structure of the country immediately prior to the Olary upwarp was very similar to that at present in existence. It is probable at this early stage that the north-south drainage was much more extensively developed than at the present day, and that the upwarp truncated this system, building up the divide between the present north-flowing and south-flowing streams.

However, it is apparent that the present streams are not completely governed by the north-south structural characteristics. At intervals they make abrupt right-angled bends to flow westward through gaps in the adjoining ridge. These gaps are often in the form of narrow gorges, the walls of which rise steeply on either side. The gradient of a stream in the gorge section is greatly increased, and rapids and even small waterfalls are common. The stream emerges from the gorge to join another southward flowing drainage system. The streams therefore cannot be regarded as having attained profiles of equilibrium, as the grades reached are separated by short ungraded sections.

This type of stream pattern is characteristic of practically the whole of the Mount Lofty and Flinders Ranges and has long been a topic for speculation. Dr. Charles Fenner, in a personal communication to the writer in 1942, stressed

the point that the phenomenon is a *general* one, and therefore that the explanation for it must also be general and not restricted to any one locality. The writer believes that some previous theories have suffered from the weakness that the data used may not have been obtained from a sufficiently wide area. In the past, all the detailed physiographic work in connection with the subject has been restricted to the Mount Lofty Ranges in the Adelaide Region, and the writer feels that the tectonic relationships peculiar to this area have at times been allowed to outweigh other geomorphic factors. In the Adelaide area the Ranges have been extensively block-faulted, whereas in County Victoria (with the exception of the South Flinders Range) block-faulting is almost non-existent. Near Adelaide the north-south valleys are to a large degree the result of this faulting, whereas in County Victoria they are due to the presence of synclines and eroded anticlines in a peneplane which has been gently uplifted.

In County Victoria, therefore—and particularly in the Jamestown district where the writer completed a detailed stratigraphical survey—any hypothesis which includes block-faulting cannot apply. Theories which regard the east-west sections of the streams as antecedent, having cut through fault-block edges during a period of uplift, are therefore untenable.

As a result of field investigation near Jamestown (Langford-Smith, 1942) the writer came to the conclusion that the explanation could be found in stream capture on an extensive scale.

More recently Sprigg (1945) has expressed the same opinion in regard to streams in the Mount Lofty Ranges in the Adelaide area, and it is submitted by the writer that in view of the conclusions of these entirely separate investigations, the general theory of stream capture should receive serious consideration.

The Jamestown district affords typical examples of the stream pattern under consideration. Therefore, in view of the fact that the structural geology of the district is known in some detail, it is considered eminently suitable for investigation in regard to the "stream capture" theory.

The accompanying block diagram (fig. 2) which is based on aerial photographs, illustrates the main physiographic features of the district. It may be noted that the Belalie Creek flows in a southerly direction down the valley to the west of the Browne Hill Range, before swinging abruptly to the west and entering a gorge in a north-south ridge. The creek has a low gradient in the north-south valley, but this increases considerably in the gorge section where there are numerous rapids, and in one place ("The Cups") a small waterfall. After leaving the gorge, Belalie Creek is joined by a small north-south creek at Jamestown, and shortly afterwards swings south again into the Baderloo Creek valley, where it enters another low gradient stage. The diagram shows how Freshwater Creek drains the valley west of the Browne Hill Range below the point where Belalie Creek swings west into the Jamestown valley.

The ridge containing the Belalie Creek gorge is a watershed for numerous small consequent streams, which flow to both east and west. All these streams show very active headward erosion and many of them have cut well back into the ridge. It is of great significance that headward erosion is especially active on streams flowing to the west of the divide. This is because the floor of the western valley is lower than that to the east, and in general stream profiles are steeper. One westward-flowing consequent stream (marked A on the diagram) has eroded its way back completely through the ridge, being assisted to some extent by the presence of a very small transverse fault. It is now commencing to cut its way into the adjoining valley floor, and its headwater zone has already captured some of the water from this valley. Before long, if headward erosion continues, it will capture the headwaters of Belalie Creek.

In the light of the foregoing evidence it is probable that Belalie Creek once flowed right down the north-south valley and did not swing westwards through the gorge near Jamestown. At this stage, Belalie Creek and Freshwater Creek would have been one continuous stream.

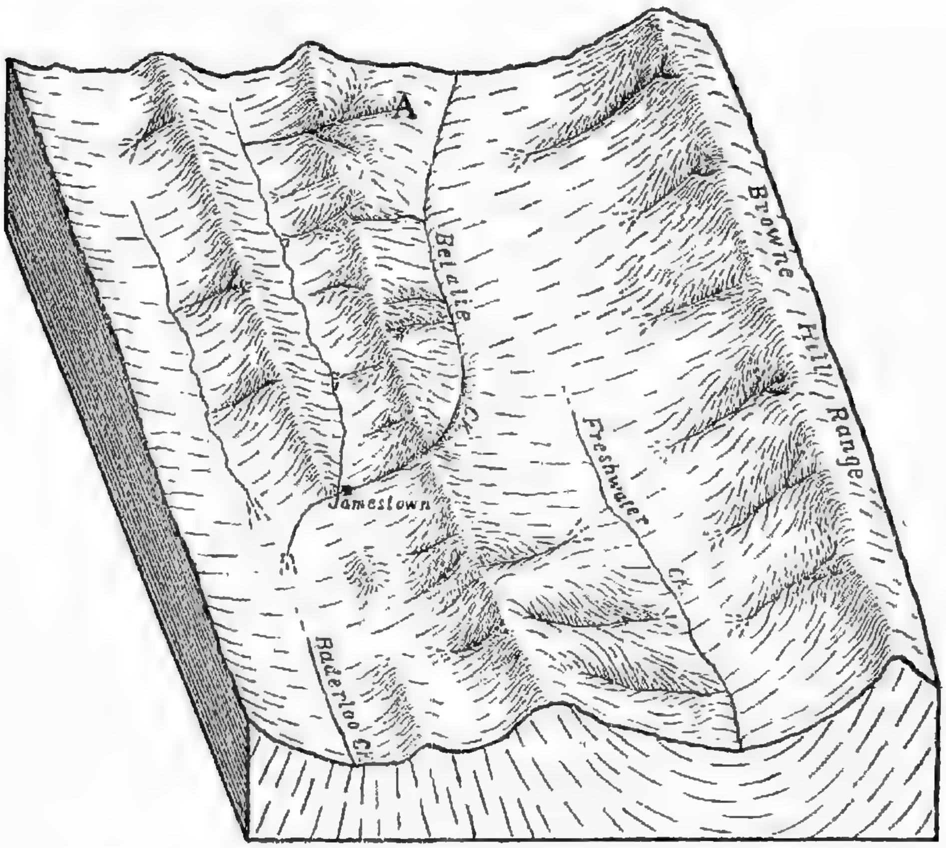

Fig. 2
Block diagram of drainage pattern near Jamestown; stream capture at A.

This is by no means an isolated case, and throughout the County east-west streams may be found in all stages of headward erosion right up to the point of capturing a north-south stream. It is not known to what extent small transverse faults have accelerated headward erosion in consequent streams by creating zones of weakness, although in a few instances this is known to have been a contributing factor, as in the example cited.

Broughton River System

Although most of its tributaries flow from or through County Victoria, the upper and middle reaches of the Broughton itself are south of the County boundary, and consequently could not be investigated thoroughly in the time available in the field. The lower reaches of the river are well within the County and were examined in rather more detail.

Unlike most of its tributaries, the Broughton flows across the grain of the country in a general east-west direction. It has its source in the high country south of the Booborowie Flats. Flowing approximately westward to Spalding,

it is met by Deep Creek and Freshwater Creek flowing from the north, and the Hill River from the south. A few miles south-west of Spalding, after being joined by the Hutt River flowing from the south, it dives through a gorge in a north-south ridge. Shortly after emerging from this gorge it is joined by the Bundaleer Creek from the north. After passing through Red Hill it is joined by Rocky River, and then flows on to the Pirie Plains where it is met by the Crystal Brook.

The course of the Broughton River over the Pirie Plains is through flood plains of its own making. An important feature of the upper parts of this section is the deep channel through which the river is at present flowing. The height of the banks, which are very steep-sided, averages about 20 feet above the stream bed (see pl. xxv, fig. 2). This down-cutting is evidence of an endeavour by the stream to regrade its course after comparatively recent uplift. The course of the Broughton River nearer the coastline is not clearly defined, and there are a number of distributaries. Meandering channels are a feature of this part. The most prominent channel is known as Deep Creek, which continues to the tidal Port Davis Creek.

A detailed description of most of the Broughton tributaries has already been recorded (Langford-Smith, 1942), and it is not proposed to discuss these at length in the present paper. However, certain features which are common to them all have particular geomorphic significance. One of these is related to the stream anomalies which have already been expounded in the discussion on "Stream Capture". Because of these anomalies, each stream is subdivided into series of gently graded reaches separated by short sections of steep gradient. Therefore, the streams (with the exception of the lower Broughton) do not have profiles of equilibrium. At each of the east-west sections of steep gradient the stream is down-cutting rapidly in an attempt to propagate upstream the break in its profile. In some cases this has already resulted in down-cutting in the north-south sections, and this will tend to continue until the whole stream system has attained a profile of equilibrium. Douglas Johnson (1938) has shown that a stream profile can only be used as an indicator of change in level when the stream itself had a profile of equilibrium prior to the uplift. In other words, the only stream in County Victoria which can be used for this purpose is the lower Broughton. However, a significant feature of nearly all the tributaries is the presence of two river terraces, one above the other. The higher terrace represents a "fossil" flood-plain originating during an earlier period. It would appear that this flood-plain is indicative of an earlier period of heavier rainfall, for as already pointed out the streams are not in equilibrium, and the almost universal down-cutting through old alluvium cannot have been caused by isostatic change. The presence of old alluvium above the present flood-plains of streams has been noted in many parts of eastern Australia, and Whitehouse in particular has assumed that it is indicative of higher rainfall periods in the Pleistocene.

The time available for field examination of the middle and upper reaches of the Broughton River was limited, and it was not possible to consider in detail the question of its origin. However, a few significant points are discussed briefly.

The most prominent feature of the Broughton is that it flows in a general east-west direction, which is apparently right across the grain of the country. This fact has led Fenner (1931) to suggest that it is an antecedent stream. Howchin has proposed that it came into being after the Olary upwarp period, as a result of extensive ponding in the low areas to the south of County Victoria. However, it is important to note that over the course followed by the Broughton, the "ridge-and-valley" structure is not as strongly developed as in areas either to the north or the south, and the river flows through very few gorges in north-

south ridges. If the river capture theory is substantiated in connection with stream anomalies in the Broughton tributaries, it would not be unreasonable to suggest that headward erosion of consequent streams may have been responsible for the few "break-throughs" in the present course of the main stream. During the period of uplift there may have been a certain amount of local ponding which could have hastened the "breaking-through" process in the case of individual ridges. In the event of ponding, the degree of headward erosion required on the part of a consequent stream would have been reduced.

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Fig. 1

The Pirie Plains, looking east from the Tidal Flats towards the South Flinders Scarp.

Fig. 2

The Napperby Pediment, with the South Flinders Scarp in the background.

Fig. 3

Looking along a typical north-south ridge near Jamestown.

Fig. 4

Looking west from the same ridge towards the Campbell Range, illustrating ridge-and-valley structure.

Fig. 1
Gravels from a residual site. Note rounded, stream-worn pebbles.

Fig. 2
Broughton River on the Pirie Plains south of Crystal Brook, showing deeply incised channel.

PURPLE SLATES OF THE ADELAIDE SYSTEM

By D. Mawson and E. R. Segnit

Summary

The nature and genesis of the shales and slates of chocolate to purple colour occurring at several distinct horizons in the post-glacial Upper-Proterozoic strata of the Adelaide System is a matter of interest. Certain features have suggested that in part they may be of tuffaceous origin. There are several factors indicating this probability, such as the unleached nature of the shale, a considerable proportion of the coarser particles being recognisable feldspar. The alkali and lime content of the rock is high. Further, we have observed that these shales in some areas at least have a notable content of barium and even copper; veins of barytes are a common associate and the occurrence of blue and green copper stains between the laminae of the shale has been observed in a number of localities. Also, among embedded rock fragments at one horizon in a belt of purplish-brown shale, fragments of a soda-rich basaltic rock were found to be common.

PURPLE SLATES OF THE ADELAIDE SYSTEM

By D. Mawson and E. R. Segnit *

[Read 11 November 1948]

The nature and genesis of the shales and slates of chocolate to purple colour occurring at several distinct horizons in the post-glacial Upper-Proterozoic strata of the Adelaide System is a matter of interest. Certain features have suggested that in part they may be of tuffaceous origin. There are several factors indicating this probability, such as the unleached nature of the shale, a considerable proportion of the coarser particles being recognisable feldspar. The alkali and lime content of the rock is high. Further, we have observed that these shales in some areas at least have a notable content of barium and even copper; veins of barytes are a common associate and the occurrence of blue and green copper stains between the laminae of the shale has been observed in a number of localities. Also, among embedded rock fragments at one horizon in a belt of purplish-brown shale, fragments of a soda-rich basaltic rock were found to be common.

However, elsewhere, throughout a considerable thickness of strata, these shales are very fine and uniform in grain and where they grade into arenites these latter are dominantly composed of quartz particles, but with a notable contribution of feldspar. In order to probe further the origin of these shales, material collected close to the old Mount Deception Station homestead on the eastern slopes of Mount Deception, 11 miles north-west of Beltana, has been analysed by one of us and otherwise more fully examined, with the results detailed herewith.

The horizon in the Adelaide System from which these specimens now subjected to detailed examination were obtained is the thick purplish-brown belt below the Cambrian Pound Quartzite, referred to by Howchin as the Purple Slates. At one place in the neighbourhood of the spot where the specimens were obtained malachite stains were observed in the bedding planes of the shales.

Of the two specimens examined, one of very fine grain represents the more normal type of this rock, while the other represents a coarser than usual band of the shale.

The finer grained variety [8126], when examined in the hand specimen, is observed to be of a dark vinaceous red colour (Ridgway) and a faintly distinguishable fine sedimentary banding. It is soft, remarkably even-grained and breaks with a smooth sub-conchoidal fracture. The microscope slide reveals that it is principally composed of grains of quartz, altered particles of feldspar and minute flecks of mica. The quartz grains are clear and frequently very angular; they tend to be concentrated in the lighter bands of the shale. The mica is clear and colourless in tiny flakes so thin as to give only red and yellow interference colours. The feldspars have evidently been largely decomposed to a featureless mass, possibly mainly composed of the kaolinite group of minerals. It is this matrix that is stained purplish-brown by the ferric oxide content of the shale, thus imparting that colour to the rock as a whole. Calcite is distinguishable, distributed throughout in irregular grains. It is sufficiently abundant to link up with the 5% of carbon-dioxide found to be contained in the rock. Also, there is present a small amount of chlorite, haematite, and a highly refracting mineral, possibly zircon.

* Geology Department, University of Adelaide.

The second [8127], coarser-grained specimen is a harder, darker purple rock. In this the mineral assemblage is similar to the preceding but the particles are larger and more determinable. There is much quartz of larger grain-size and frequently very angular; also fresh feldspar in grains of similar size and shape. These mineral grains are cemented in an abundant matrix of dark-red iron oxide with which is an association of mica fragments and serpentinous material. The more obvious feldspar is twinned plagioclase, the majority of which is characterised by a low R.I. and an extinction angle on albite twins of 12°-14°, indicating a rather sodic variety. Microcline and orthoclase are also present. The untwinned feldspar is only with difficulty distinguished from the quartz when all is embedded in the dark matrix. Though very fine-grained this rock probably comes within the silt grade.

An analysis of the finer-grained variety is stated herewith, and included in the table are analyses of other relevant shales and of a red micro-granite.

Publications dealing with the origin of red rocks are comparatively few. It is generally agreed, however, that the red colour is due to the presence of ferric oxide, either hydrated as some form of limonite or anhydrous as hematite (Dorsey 1926, and Raymond 1942). Thus arises the question of the derivation of the ferric oxide. Raymond (1927) deals at length with this matter, stressing the widespread development of highly ferruginous laterites under warm moist conditions as an abundant source of ferric oxide. He also discusses the development of ferric oxide in arid regions, as is evidenced by the red colour of sands and rocks in such areas.

Recently Lord Rayleigh (1946) has investigated the cause of the red colour of certain sandstones and finds that if chalybeate water is evaporated on the surface of a solid body, *e.g.*, a sand grain, a red coating results. The same red colouration develops when evaporation takes place in air from an undisturbed liquid surface. If on the other hand evaporation of chalybeate waters takes place in an agitated liquid, as in a stream in the open, the iron separates as a light yellow precipitate.

It is thus obvious that sand particles moistened by waters containing some ferrous bicarbonate in solution and dried out will be reddened. From this it would appear also that argillaceous deposits in chalybeate waters evaporating in shallow playa lakes would be reddened.

So red shales and sandstones can be accumulated either *in situ* as terrestrial deposits or can be derived from the transport of such peroxidised materials and their subsequent deposition under non-reducing conditions. This also would normally imply a terrestrial origin, but in special cases, where organic life is much subordinated or non-existent, deposition might conceivably take place as shallow-water marine deposits adjacent to large land masses.

In our case the red-brown colour is given to the shale by the presence of the remarkably small amount of 1·94% of ferric oxide, which amount is unusually low for a shale and particularly so for red varieties (see table of analyses).

It is interesting to note that certain bright-red to chocolate-coloured igneous rocks may contain extremely little ferric oxide, as for example the porphyritic micro-granite [5778] (Mawson and Segnit 1946), containing only 0·92%. Further, it is possible for a green slate to contain the high proportion of 3·48% ferric oxide (see table of analyses). In this latter case it must be present in a combination with other constituents.

	I	II	III	IV	V	VI	VII
SiO_2	58·30	58·38	60·96	56·49	68·64	38·98	72·50
TiO_2	15·64	0·65	0·86	0·48	0·56	2·05	0·08
Al_2O_3		15·47	16·15	11·59	11·33	28·00	14·02
Fe_2O_3	1·94	4·03	5·16	3·48	3·07	14·39	0·92
FeO	2·80	2·46	2·54	1·42	0·73	0·98	1·24
MgO	3·87	2·45	3·20	6·43	2·40	0·36	0·23
CaO	4·31	3·12	0·71	5·11	3·50	0·15	0·77
Na_2O	1·81	1·31	1·50	0·52	1·51	0·08	3·47
K_2O	3·16	3·25	5·01	3·77	2·10	0·18	5·24
H_2O+	2·56	5·02	3·08	2·82	2·27	10·38	0·73
H_2O-	0·30		0·17	0·37		3·60	0·18
P_2O_5	0·16	0·17	0·23	0·09	0·15	0·06	0·06
MnO	0·10	—	0·07	0·30	0·06	0·04	0·04
BaO	0·10	0·05	0·03	0·06	—	tr.	0·07
ZrO_2	—	—	—	—	—	0·01	—
CuO	0·02	—	—	—	—	0·11	—
Cr_2O_3	—	—	—	—	—	0·06	—
NiO	nil	—	—	—	—	0·01	—
Fl	—	—	—	—	—	nil	0·08
Cl	0·01	—	—	—	0·04	0·15	—
SO_3	—	—	—	—	0·31	0·01	—
S (Sulphide)	0·02	—	—	—	—	0·05	—
CO_2	5·13	2·64	0·68	7·42	3·35	0·22	0·80
C	—	—	—	—	0·11	—	—
	100·24	100·00	100·23	100·38	100·13	99·91	100·47
Less O for F, Cl & S	—	—	—	—	0·01	0·05	·03
Total	100·24	100·00	100·23	100·38	100·12	99·86	100·44

I. Purple slate from Mount Deception, S. Aust. Analyst, E. R. Segnit.
II. Average of 78 shales (Clarke, p. 631).
III. Purple slate, Castleton, Vermont (Clarke, p. 554).
IV. Green slate near Janesville, N.Y. (Clarke, p. 554).
V. Mean of analysis of two samples of Pleistocene loess, respectively from Illinois and Iowa. Clarke (p. 514).
VI. Triassic chocolate shale, Long Reef, N.S.W. (Walton, 1906).
VII. A red-brown, potash-soda micro-granite (Mawson and Segnit, 1946).

Chocolate-coloured shales diagnosed as probably redistributed tuffs are well known in the Triassic Narrabeen Series[1] of the Sydney Basin (see table of analyses). Such reddish, tuffaceous shales appear always to be associated with basic volcanic activity and the high content of ferric oxide is deemed sufficient to cause the red colouration.

There is nothing very unusual in the chemical composition of our purple slate, but three interesting features do stand out. The first is the very low proportion of ferric oxide. The second is the higher than usual amount of barium which is accounted for by the fact that a large area of South Australia, including the Flinders Ranges, is a barium-rich petrological province. The third feature is that the common elements more soluble under normal conditions of weathering, namely calcium, sodium and potassium are significantly high. This may be taken as implying that the detritus which contributed to the formation of the shale originated from erosion either under arid or glacial conditions or was partly, at least, in the nature of volcanic dust. The presence of copper rather suggests the latter, but may result from the evaporation and concentration of leachings under arid conditions.

The chemical and mineral composition of this shale does not correspond with what would be expected if it were of volcanic origin. The iron content is too low in relation to that of calcium and magnesium for any common igneous type. Also, the quantity of free quartz is excessive in relation to the magnesium. Such feldspar fragments as are discernible indicate contributions from granites and acid gneisses, not from basalts. There is, therefore, little support for the suggestion that volcanic ash may have contributed notably to the formation of these chocolate shales.

Reverting to consideration of the shape of the mineral particles in the shale, they are sometimes strikingly angular; some actually are long and thin-splintery. They evidently have not undergone prolonged transportation or weathering. The shape of the grains denotes material derived directly from a primary source.

It is interesting to record (Hatch, Rastall and Black, 1938) that quartz grains may take two or three cycles of weathering and transportation before being appreciably rounded. Further, as stated by Twenhofel (1945), grains of quartz of sand size are very little or not rounded in stream transport, and that grains 0·25 mm. in diameter or less are very little if at all rounded in aqueous transportation on sea or lake shores.

In the case of our slates there is no evidence of excessive rounding of mineral grains such as the millet seed sands of desert areas. But this would not be expected to apply to the excessively fine-grained material constituting this shale.

The field nature of these belts of shale and slate is favourable to a loessial origin. They are deposits of great thickness and homogeneity and of even grain-size. In some localities they are so uniform in texture that there may be little trace of bedding planes. At other times the slight difference in grain-size observed in successive faint laminae may represent dust transported under varying wind force.

The lower purple series of our Adelaide System have distributed throughout recurrent thin calcareous, dolomitic and sideritic bands which, as evidenced by their porphyroplastic clay wisps and pellets, are clearly of very shallow-water terrestrial origin. We conclude that the evidence favours a terrestrial loessial origin for the chocolate shale belts of the Adelaide System.

[1] Reference to these shales has appeared since this paper was compiled. See Presidential Address of Dr. G. D. Osborne, Proc. Roy. Soc N.S.W., 73, 1948.

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RECEIPTS

	£	s.	d.	£	s.	d.
To Balance, 1 Oct., 1947				106	15	8
,, Subscriptions				154	11	2
,, Government Grant for Printing, etc.				400	0	0
,, Sale of Publications and Reprints—						
University of Adelaide	32	2	9			
Sundries	40	19	0	73	1	9
,, Interest: Transferred from Endowment Fund				204	19	0
				£939	7	7

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	£	s.	d.	£	s.	d.
By Transactions (Printing and Publishing Vol. 71, Pt. 2; Vol. 72, Pt. 1)				713	17	10
,, Reprints				68	8	10
,, Librarian				36	6	0
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,, Notice Board				9	18	6
,, Reflectors				4	19	2
,, Sundries—						
Printing and Postage, etc.	32	4	3			
Lighting	3	16	2			
Petties	9	5	2			
Insurances	6	10	0			
Cleaning Rooms	12	10	0	64	5	7
,, Balances 30 Sept. 1948:						
Savings Bank of S.A.	7	18	0			
Bank of Australasia—General A/c. .. £14 13 8						
Less Outstanding Cheque 1 0 0	13	13	8	21	11	8
				£939	7	7

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Capital—Stock, etc., Face Value £6,042/18/7; Cost £6,041/8/7

	£	s.	d.	£	s.	d.
1947—October 1						
To Balance—						
Australian Inscribed Stocks	6,008	10	0			
Savings Bank of S.A.	32	18	7	6,041	8	7
,, Interest—						
Inscribed Stocks	200	9	6			
Savings Bank of S.A.	4	9	6	204	19	0
				£6,246	7	7

	£	s.	d.	£	s.	d.
1948—September 30						
By Revenue Account ..				204	19	0
,, Balance—						
Australian Inscribed Stocks	6,008	10	0			
Savings Bank of S.A.	32	18	7	6,041	8	7
				£6,246	7	7

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HERBERT M. HALE, Hon. Treasurer

Adelaide, October, 1948

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1944. CORNISH, MELVILLE, State Bank, Pirie Street, Adelaide.
1929. *COTTON, B. C., S.A. Museum, Adelaide—*Council*, 1943-46, 1948-.
1924. DE CRESPIGNY, SIR C. T. C., D.S.O., M.D., F.R.C.P., 219 North Terrace, Adelaide.
1937. *CROCKER, R. L., D.Sc., Waite Institute (Private Mail Bag), Adelaide—*Secretary*, 1943-45; *Council*, 1945-47.
1941. *DICKINSON, S. B., M.Sc., Govt. Geologist, Mines Department, Flinders Street, Adelaide—*Council*, 1946-.
1930. DIX, E. V., Hospitals Department, Rundle Street, Adelaide, S.A.
1944. DUNSTONE, S. M. L., M.B., B.S., 124 Payneham Road, St. Peters, Adelaide.
1931. DWYER, J. M., M.B., B.S., 105 Port Road, Hindmarsh, S.A.
1933. *EARDLEY, Miss C. M., B.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1943-46.
1945. *EDMONDS, S. J., B.A., M.Sc., 56 Fisher Terrace, Mile End, S.A.
1902. *ENQUIST, A. G., 19 Farrell Street, Glenelg, S.A.
1944. FERRES, MISS H. M., M.Sc., 8 Taylor's Road, Mitcham, S.A.
1927. *FINLAYSON, H. H., 305 Ward Street, North Adelaide—*Council*, 1937-40.
1923. *FRY, H. K., D.S.O., M.D., B.S., B.Sc., F.R.A.C.P., Town Hall, Adelaide—*Council*, 1933-37; *Vice-President*, 1937-38, 1939-40; *President*, 1938-39.
1932. *GIBSON, E. S. H., B.Sc., 297 Cross Roads, Clarence Gardens, Adelaide.
1935. *GLASTONBURY, J. O. G., B.A., M.Sc., Dip.Ed., Beatty Terrace, Murray Bridge, S.A.
1927. GODFREY, F. K., Box 951H, G.P.O., Adelaide.
1935. †GOLDSACK, H., Coromandel Valley, S.A.
1939. GOODE, J. R., B.Agr.Sc., P.O. Box 180, Whyalla, S.A.
1925. †GOSSE, SIR JAMES H., Gilbert House, Gilbert Place, Adelaide.
1910. *GRANT, PROF. SIR KERR, M.Sc., F.I.P., 56 Fourth Avenue, St. Peters, S.A.
1930. GRAY, J. T., Orroroo, S.A.
1933. GREAVES, H., 12 Edward Street, Glynde, S.A.
1904. GRIFFITH, H. B., Dunrobin Road, Brighton, S.A.
1948. GROSS, G. F., South Australian Museum, Adelaide.
1944. GUPPY, D. J., B.Sc., Mineral Resources Survey, Canberra, A.C.T.
1922. *HALE, H. M. Director, S.A. Museum, Adelaide—*Verco Medal*, 1946; *Council*, 1931-34; *Vice-President*, 1934-36, 1937-38; *President*, 1936-37; *Treasurer*, 1938-
1949. HALL, D. R., Mern Merna, via Quorn, S.A.
1946. *HARDY, MRS. J. E. (nee A. C. Beckwith), M.Sc., Box 62, Smithton, Tas.
1944. HARRIS, J. R., B.Sc., 94 Archer Street, North Adelaide, S.A.
1947. HENDERSON, D. L. W., Craigstone, Woodford, N.S.W.
1944. HERRIOT, R. I., B.Agr.Sc., Soil Conservator, Dept. of Agriculture, S.A.
1949. HOLLOWAY, B. W., B.Sc., 33 Kyre Avenue, Kingswood, S.A.
1924. *HOSSFELD, P. S., M.Sc., 132 Fisher Street, Fullarton, S.A.
1944. HUMBLE, D. S. W., 238 Payneham Road, Payneham, S.A.
1947. HUTTON, J. T., B.Sc., 13 Sherbourne Road, Medindie Gardens, S.A.
1928. IFOULD, P., Kurralta, Burnside, S.A.
1942. JENKINS, C. F. H., Department of Agriculture, St. George's Terrace, Perth, W.A.
1918. *JENNISON, REV. J. C., 7 Frew Street, Fullarton, Adelaide.
1945. *JESSUP, R. W., B.Sc., 3 Alma Road, Fullarton, S.A.
1910. *JOHNSON, E. A., M.D., M.R.C.S., "Tarni Warra," Port Noarlunga, S.A.
1921. *JOHNSTON, PROF. T. H., M.A., D.Sc., University of Adelaide—*Verco Medal*, 1935; *Council*, 1926-28, 1940-; *Vice-President*, 1928-31; *President*, 1931-32; *Secretary*, 1938-40; *Rep. Fauna and Flora Board*, 1932-39; *Editor*, 1943-45.
1939. †KHAKHAR, H. M., Ph.D., M.B., F.R.G.S., Khakar Buildings, C.P. Tank Road, Bombay, India.
1933. *KLEEMAN, A. W., M.Sc., University of Adelaide—*Secretary*, 1945-48; *Vice-President*, 1948-.
1922. LENDON, G. A., M.D., B.S., F.R.C.P., A.M.P. Building, King William Street, Adelaide.
1948. LOTHIAN, T. R. N., N.D.H. (N.Z.), Director, Botanic Gardens, Adelaide.
1949. LOWER, H. F., 7 Avenue Road, Highgate, S.A.
1931. *LUDBROOK, MRS. W. V. (nee N. H. Woods), M.A., Elimatta Street, Reid, A.C.T.

Date of Election.

1948. McCulloch, R. N., M.B.E., B.Sc. (Oxon.), B.Agr.Sci. (Syd.), Roseworthy Agricultural College, S.A.
1938. Madbern, C. B., B.D.S., D.D.Sc., Shell House, North Terrace, Adelaide.
1932. Mann, E. A., C/o Bank of Adelaide, Adelaide.
1939. Marshall, T. J., M.Agr.Sc., Ph.D., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1948-.
1929. Martin, F. C., M.A., Technical High School, Thebarton, S.A.
1905. *Mawson, Prof. Sir Douglas, O.B.E., D.Sc., B.E., F.R.S., University of Adelaide—*Verco Medal*, 1931; *President*, 1924-25, 1944-45; *Vice-President*, 1923-24, 1925-26; *Council*, 1941-43.
1920. Mayo, The Hon. Mr. Justice, LL.B., K.C., Supreme Court, Adelaide.
1943. McCarthy, Miss D. F., B.A., B.Sc., 70 Halton Terrace, Kensington Park.
1944. †*Miles, K. R., D.Sc., F.G.S., Mines Department, Flinders Street, Adelaide.
1939. Mincham, V. H., Hammond, S.A.
1925. †Mitchell, Prof. Sir W., K.C.M.G., M.A., D.Sc., Fitzroy Ter., Prospect, SA.
1933. Mitchell, Prof. M. L., M.Sc., University, Adelaide.
1938. Moorhouse, F. W., M.Sc., Chief Inspector of Fisheries, Flinders Street, Adelaide.
1940. Mortlock, J. A. T., 37 Currie Street, Adelaide.
1936. *Mountford, C. P., 25 First Avenue, St. Peters, Adelaide.
1944. Murrell, J. W., Engineering and Water Supply Dept., Port Road, Thebarton, S.A.
1944. Neal-Smith, C. A., B.Agr.Sci., 16 Gooreen Street, Reid, Canberra, A.C.T.
1944. Ninnes, A. R., B.A., 62 Sheffield Street, Malvern, S.A.
1945. *Northcote, K. H., B.Agr.Sc., A.I.A.S., 6 Charles Street, Forestville,S.A.
1930. Ockenden, G. P., c/o Flinders Street Practising School, Flinders Street, Adelaide.
1947. *Ophel, I. L., 65 Fifth Avenue, St. Peters, S.A.
1913. *Osborn, Prof. T. G. B., D.Sc., Department of Botany, Oxford, England—*Council*, 1915-20, 1922-24; *President*, 1925-26; *Vice-President*, 1924-25, 1926-27.
1937. *Parkin, L. W., B.Sc., c/o Mines Department, Flinders Street, Adelaide.
1945. Pattison, G., 68 Partridge Street, Glenelg, S.A.
1929. Paull, A. G., M.A., B.Sc., 10 Milton Avenue, Fullarton, S.A.
1926. *Piper, C. S., D.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1941-43; *Vice-President*, 1943-45, 1946-47; *President*, 1945-46.
1948. Powrie, J. K., B.Sc., C.S.I.R.O., Division of Biochemistry, University, Adelaide.
1947. Poynton, J. O., M.D., M.A., Ch.B., M.R.C.S., L.R.C.P., University of Adelaide.
1925. *Prescott, Prof. J. A., C.B.E., D.Sc., A.I.C., Waite Institute (Private Mail Bag), Adelaide—*Verco Medal*, 1938; *Council*, 1927-30, 1935-39; *Vice-President*, 1930-32; *President*, 1932-33.
1926. Price, A. G., C.M.G., M.A., Litt.D., F.R.G.S., 46 Pennington Terrace, North Adelaide.
1945. Pryor, L. D., M.Sc., Dip.For., 32 La Perouse Street, Griffith, N.S.W.
1944. Riceman, D. S., B.Agr.Sc., C.S.I.R.O., Division of Nutrition, Adelaide.
1947. Riedel, W. R., B.Sc., St. Mark's College, Pennington Terrace, North Adelaide.
1948. Rimes, G. D., 24 Winston Avenue, Clarence Gardens, S.A.
1947. Rix, C. E., 42 Waymouth Avenue, Glandore, S.A.
1946. Robinson, E. G., B.Sc., 42 Riverside Drive, Sudbury, Ontario, Canada.
1945. Rymill, J. R., Old Penola Estate, Penola, S.A.
1944. *Sandars, Miss D. F., M.Sc., University of Queensland, Brisbane, Queensland.
1933. Schneider, M., M.B., B.S., 175 North Ter., Adelaide.
1946. *Segnit, E. R., M.Sc., C.S.I.R.O., Division of Industrial Chemistry, Box 4331, G.P.O. Melbourne, Victoria.
1924. *Segnit, R. W., M.A., B.Sc., Engineering and Water Supply Department, Victoria Square, Adelaide—*Secretary*, 1930-35; *Council*, 1937-38; *Vice-President*, 1938-39, 1940-41; *President*, 1939-40.
1925. *Sheard, H., Port Elliot, S.A.
1936. *Sheard, K., Fisheries Research Div., C.S.I.R.O., c/o Institute of Agriculture, Univ., W.A.
1945. Shepherd, J. H., B.Sc., B.A., c/o Zinc Corporation, Broken Hill, N.S.W.
1934. Shinkfield, R. C., Salisbury, S.A.
1924. Simpson, F. N., Pirie Street, Adelaide.
1941. *Smith, T. Langford-, B.Sc., Department of Post-War Reconstruction, Canberra, A.C.T.
1941. Southcott, R. V., M.B., B.S., 13 Avenue Road, Unley Park, S.A.
1936. Southwood, A. R., M.D., M.S. (Adel.), M.R.C.P., Wootoona Ter., Glen Osmond, S.A.
1947. *Specht, R. L., B.Sc., 15 Main Road, Richmond, S.A.
1936. *Sprigg, R. C., M.Sc., Mines Department, Flinders Street, Adelaide.
1947. Spurling, M. B., B.Sc., Department of Agriculture, Adelaide.

Date of Election.

1938. *STEPHENS, C. G., M.Sc., Waite Institute (Private Mail Bag), Adelaide.
1935. STRICKLAND, A. G., M.Agr.Sc., 11 Wootoona Terrace, Glen Osmond, S.A. *Council*, 1947-.
1932. SWAN, D. C., M.Sc., Waite Institute (Private Mail Bag), Adelaide—*Secretary*, 1940-42; *Vice-President*, 1946-47, 1948-; *President*, 1947-48.
1948. SWANN, F. J. W., 38 Angas Road, Lower Mitcham, S.A.
1934. SYMONS, I. G., 35 Murray Street, Lower Mitcham, S.A.—*Editor*, 1947-.
1929. *TAYLOR, J. K., B.A., M.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1940-43, 1947-.
1948. THOMAS, I. M., M.Sc. (Wales), University, Adelaide. *Secretary*, 1948-.
1938. *THOMAS, MRS. I. M., (nee P. M. Mawson), M.Sc., 12 Broadway, Glenelg.
1940. THOMSON, CAPT. J. M., 135 Military Road, Semaphore South, S.A.
1923. *TINDALE, N. B., B.Sc., South Australian Museum, Adelaide—*Secretary*, 1935-36; *Council*, 1946-47; *Vice-President*, 1947-48; *President*, 1948-.
1945. TIVER, N. S., B.Agr.Sc., Waite Institute (Private Mail Bag), Adelaide.
1937. *TRUMBLE, PROF. H. C., D.Sc., M.Agr.Sc., Waite Institute (Private Mail Bag), Adelaide—*Council*, 1942-1945; *Vice-President*, 1945-46, 1947-48; *President*, 1946-47.
1925. TURNER, D. C., Brookman Buildings, Grenfell Street, Adelaide.
1912. *WARD, L. K., I.S.O., B.A., B.E., D.Sc., 22 Northumberland Avenue, Tusmore—*Council*, 1924-27, 1933-35; *Vice-President*, 1927-28; *President*, 1928-30.
1941. *WARK, D. C., M.Agr.Sc., Div. Plant Industry, C.S.I.R.O., Canberra, A.C.T.
1936. WATERHOUSE, MISS L. M., 35 King Street, Brighton, S.A.
1939. *WEEDING, REV. B. J., P.O. Box 51, Minlaton, S.A.
1946. WHITTLE, A. W. G., B.Sc., Mines Department, Flinders Street, Adelaide.
1946. *WILSON, A. F., M.Sc., University of Adelaide.
1938. *WILSON, J. O., C.S.I.R.O., Division of Nutrition, Adelaide.
1930. *WOMERSLEY, H., F.R.E.S., A.L.S. (*Hon. causa*), S.A. Museum, Adelaide—*Verco Medal*, 1943; *Secretary*, 1936-37; *Editor*, 1937-43, 1945-47; *President*, 1943-44, *Vice-President*, 1944-45; *Rep. Fauna and Flora Protection Committee*, 1945.
1944. *WOMERSLEY, H. B. S., M.Sc., 43 Carlisle Road, Westbourne Park, S.A.
1944. WOMERSLEY, J. S., B.Sc., Lae, New Guinea.
1923. *WOOD, PROF. J. G., D.Sc., Ph.D., University of Adelaide—*Verco Medal*, 1944; *Council*, 1938-40; *Vice-President*, 1940-41, 1942-43; *Rep. Fauna and Flora Board*, 1940-; *President*, 1941-42; *Council*, 1944-48.
1943. WOODLANDS, HAROLD, Box 989 H, G.P.O., Adelaide.
1945. WORTHLEY, B. W., B.A., M.Sc., A. Inst. P., University, Adelaide.
1948. WYMOND, A. P., 4 Woodley Road, Glen Osmond, S.A.
1942. ZIMMER, W. J., Dip.For., F.L.S. (Lon.), 22 Docker Street, Wangaratta, Vict.

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Names of genera and species in italics denote that the forms described are new to science.